Ruef

GEOLOGY AND WATER RESOURCES OF THE SAN JUAN ISLANDS,

San Juan County Washington

Edited by ROBERT H. RUSSELL

Washington Department of Ecology
Office of Technical Services
Water Supply Bulletin No. 46
1975

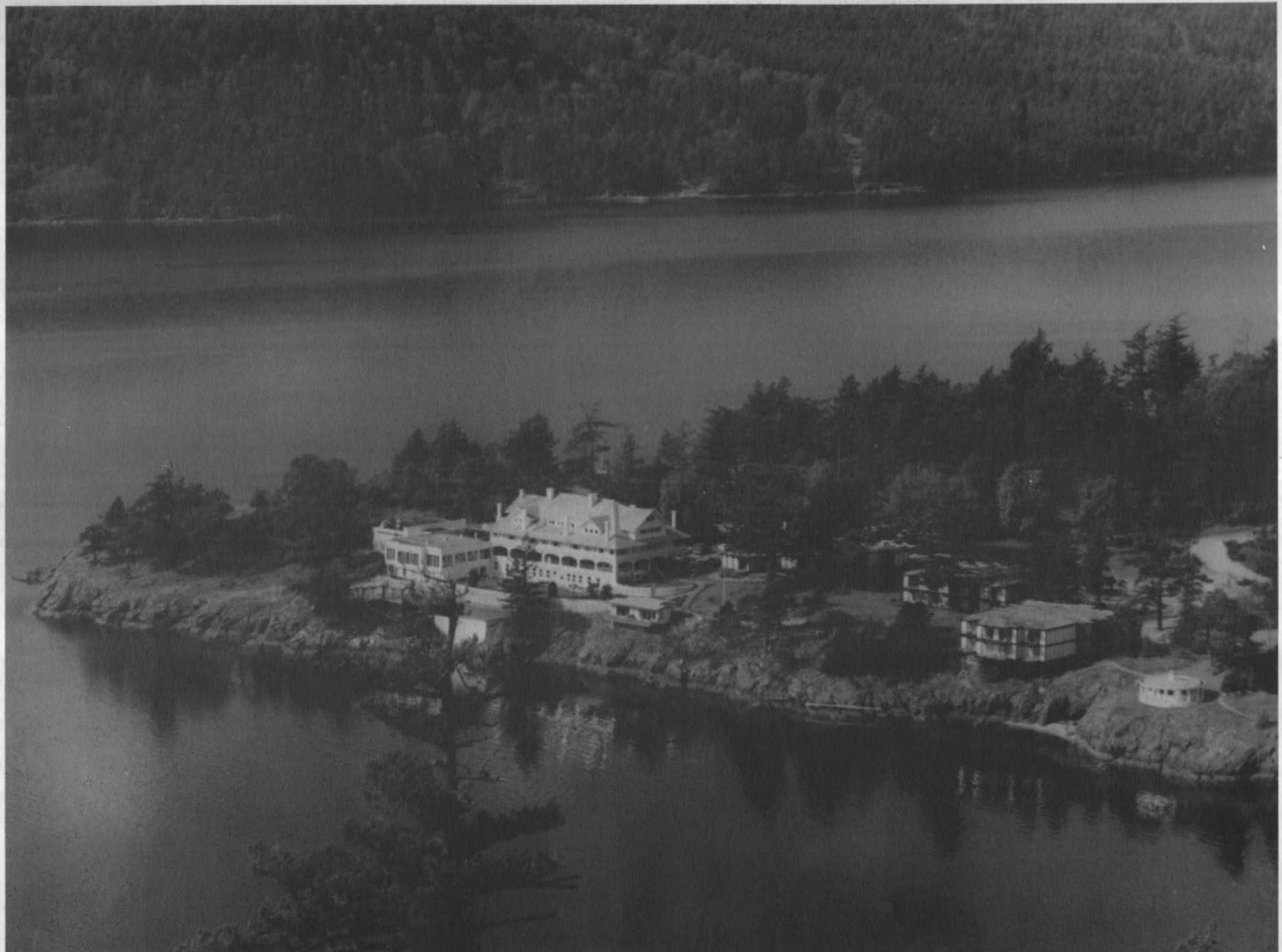
Cover—

"Overview of the San Juan Islands, Looking North"

"Cover photo courtesy of Washington Department
of Commerce and Economic Development."

LOOKING EAST TO MT. BAKER FROM MT. CONSTITUTION

Photo Courtesy of Washington Department of Commerce and Economic Development.



Rosario Resort on Orcas Island. Photo by Washington Department of Commerce and Economic Development.

State of Washington
Daniel J. Evans, Governor

Department of Ecology
John A. Biggs, Director

Water Supply Bulletin No. 46

GEOLOGY and WATER RESOURCES of THE SAN JUAN ISLANDS,

San Juan County, Washington

Edited by Robert H. Russell

with contributions by the
UNITED STATES GEOLOGICAL SURVEY

Publication Supported by Water Supply and Waste Section
Washington Department of Social and Health Services

1975

For Sale by Department of Ecology, Olympia, Wa.

Price: $5.00

FOREWORD

Those few privileged geologists who have had the good fortune to spend a part of their professional careers working in the San Juan Islands of Washington State must come away from their San Juan experience with at least two strong impressions that time will not dim or erode.

1. The majestic beauty of the San Juans is unexcelled anywhere and while there you have the feeling that their creator had intended "time to stand still". Once you have visited the San Juans, you will someday return. One is reminded of the words of Rudyard Kipling, "When the wind is in the palm trees and the temple bells they say, Come ye back ye British soldier, come ye back to Mandalay."
2. One develops a great admiration and respect for Dr. Roy C. McClellan, pioneer geologist who first mapped the San Juan Islands in the mid 1920's. The scope and quality of Dr. McClellan's work, accomplished under extremely primitive mapping circumstances, is testimony to the man's professional ability and dedication to a cause.

Although the primary purpose of the San Juan County study is to inventory the water resources of the project area, material is presented in a format designed to assist city and county government, planners and developers and others with the location of sand and gravel deposits, stone quarries and other construction materials as well as identifying slide prone areas and other environmental problems that may be encountered.

Working with the people who gave so freely of their professional abilities to the San Juan project has been a pleasant and rewarding experience. Especially, the artistic abilities of John C. Milhollin, whose illustrations brought life to the inanimate words of the geologist, is sincerely appreciated. Tireless and dedicated manuscript typing by Barbara Jansen and Beverly Jolley made the task much easier and the product better.

Water Supply Bulletin 46 is respectively submitted to provide a better understanding of the water resources of San Juan County and to serve as a base from which San Juan County planning and development can proceed in an orderly and intelligent manner with a minimum impact on the people, the environment and the unique aesthetic values of the San Juan Islands.

ROBERT H. RUSSELL, Editor, Department of Ecology

Page

TABLES

PART III — THE GEOLOGY OF THE SOUTHEASTERN SAN JUAN ISLANDS

ILLUSTRATIONS

PART IV — SURFACE WATER RESOURCES OF SAN JUAN COUNTY

ILLUSTRATIONS

TABLES

PART V — QUALITY OF WATER OF SAN JUAN COUNTY

Geology & Water Resources of San Juan County

by

Robert H. Russell, Editor, & Others

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The water resource evaluation of those islands of the San Juan group which comprise San Juan County was made by the Washington State Department of Ecology with contributions by the U.S. Geological Survey, University of Washington and the Washington State Water Research Center. It is a part of the Department's continuing program to describe and evaluate the state's water resources, both surface water and ground water, on a quantitative and qualitative basis.

The ever increasing popularity of the San Juan Islands as a residential and marine oriented recreational area prompted the San Juan County Planning Department to request the DOE to conduct a geohydrologic study of the Islands to provide the basic data and information from which a county wide water and sewer plan may be developed.

The San Juan County geology and water resource study was carried out under the direct supervision of Robert H. Russell, Project Supervisor, Office of Technical Services, Department of Ecology and under the general direction of John R. Raymond, Supervisor, Division of Water Investigations.

Surface water resources, stream gaging stations, reservoir sites and water quality evaluations were the responsibility of Peder Grimstad, assisted by Bill Dietrich, Bill Fabish and Mike Tomlinson.

Paul Eddy, assisted by Roger LeClerc and Bill Purvis, was responsible for interpreting Pleistocene geology and evaluating the ground-water resources of the project area on a regional basis.

Regional bedrock geology and Pleistocene geology of Lopez, Decatur, Blakely and other small, nearby islands was done by Dr. John Whetten, Department of Geological Sciences, University of Washington and his assistant, Paul Carroll, under a Memorandum Agreement between the DOE and the University of Washington through the Washington State Water Research Center.

John Noble of Robinson & Noble and Timothy Lovseth, University of Washington graduate student, under contract with the San Juan County Planning Department, compiled a preliminary geologic map of San Juan County based on McClellan's thesis updated from recent University of Washington student mapping and by Dr. Joseph Vance of the Department of Geological Sciences. Noble also prepared a tabulation of all water rights of record with the DOE which were appurtenant to lands within San Juan County.

John Cummans of the U.S. Geological Survey coordinated site selection and installation of staff gages at stream gaging sites and assisted with water quality monitoring station selections. He also assisted with stream flow analysis.

The San Juan County Project was begun in January, 1974, within a completion time-frame of one calendar year. Stream gaging and water quality monitoring stations were established in January and collection of water quantity and quality data was started immediately.

Geologic mapping, well scheduling and surficial aquifer evaluation was carried out in the summer and fall of 1974 by John Whetten and Paul Eddy. Field mapping was limited to the extent required to verify geologic mapping and interpretations of McClellan, Vance and others. Where there were no disagreements with the work of previous geologists, their mapping was accepted and incorporated as presented. Where there were areas of serious disagreement, sufficient additional mapping was carried out to justify all age dates and/or nomenclature changes proposed. The updating of the bedrock lithology of Lopez and other nearby islands by John Whetten will provide a valid reference area for later geologists who seek to update the work of McClellan and others who have worked in the San Juans.

Maps, illustrations and figures are by John C. Milhollin, C.E.T., Department of Ecology.

LOCATION AND EXTENT OF AREA

San Juan County is located in the northwestern part of Washington State between the mainland of Washington and Vancouver Island, Canada. The land area is made up entirely of islands which are a part of the San Juan archipelago. San Juan County has a total area of 265 miles and a land area of 172 square miles.

There are 428 islands exposed at high tide within San Juan County of which approximately 175 are named (McClellan, 1927). The three largest islands are Orcas (36,432 acres), San Juan (35,448 acre) and Lopez (18,847 acres). Other islands of 1,000 acres or more in area are Shaw, Blakely, Waldron, Decatur, Stuart and Henry, listed in order of relative size (Wolcott, 1965). Other islands range downward to less than one acre in size. Many are merely rock outcrops which are surface expressions of peaks of a sub-marine mountain range probably associated with the Olympic Mountains. Erosion of the tough, resistant bedrock which dominates the cores and shorelines of the islands is principally responsible for their picturesque, rockbound coasts which may be characteristically referred to as "San Juan topography".

Land surface elevations in San Juan County range from sea level to 2,409 feet at the summit of Mt. Constitution on Orcas Island. Lopez Hill, elevation 535′ is the highest point on Lopez Island and Blakely Peak in the northeast part of Blakely Island reaches an elevation of 1,050 feet.

Most of the intermontane valleys and lowland areas of the three large islands, San Juan, Orcas and Lopez express a low, rolling topography and are underlain by a few feet to several hundred feet of glacially derived sand, gravel and clays associated with the advance and recession of the latest continental glaciers that rode over the area from the north and east. This is in sharp contrast to the mountainous terrain dominated by bedrock at or near the land surface.

Prior to the advance of continental ice, during Pleistocene time, some of today's San Juan Islands were actually two or more individual rock islands. The advancing ice filled some inter-island waterways with glacial drift and connected individual islands with causeways. An excellent example is where the two major bedrock lobes of Orcas Island are bridged at Eastsound. Similar island bridging no doubt occurred on San Juan, Lopez, Shaw, Decatur and other islands during the same period.

PART I

Bedrock Geology of San Juan County

by

Joseph A. Vance

INTRODUCTION

The geologic map of San Juan County which accompanies this report is based in part on studies carried out under my supervision in connection with the University of Washington geology field course over six seasons between 1958 and 1973. Detailed mapping was done on Orcas, the northern part of San Juan, Henry, Jones and several smaller islands. Geology on the southeastern islands was mapped in 1974 by John Whetten. For the other islands and those not yet studied in detail the map is based on the early reconnaissance investigation of Roy D. McLellan (1927) and on several unpublished University of Washington senior theses and M.S. research papers and theses.

Although detailed field mapping of the San Juan Group is not yet complete, there is a growing demand from the general public, from geologists and from those concerned with land use and the environment for a current map of the islands and for an outline of present knowledge of the major rock units and their geologic relations. McLellan's classic report and geologic map of the islands are no longer in print and have largely become outdated in the light of more recent studies. The other major reference to San Juan geology, W. R. Danner's *Limestone Resources of Western Washington* 1966, is a valuable source of detailed stratigraphic and paleontologic data on the limestones of the San Juans, but does not provide an integrated overview of the stratigraphic and structural problems of the area as a whole. Other published geological references to the San Juan Islands are mostly scattered through the literature and are not readily accessible to the layman. It is hoped that the present map and generalized account of San Juan geology will help fill the present need.

It is to be emphasized that the accuracy of this compilation varies considerably in different areas and that the geology of some of the islands and the description of certain of the geologic units is based on sketchy reconnaissance or on secondary sources which have not been personally confirmed by the writer. The reader should also be aware that there are major differences of opinion among geologists now working in San Juan geology. These differences concern the age and structural relations of certain of the stratigraphic units and the significance of the San Juan Islands in the regional structural framework and arise from the absence of fossils or other evidence with which to date key units as well as from the tectonic complexity of the area. Many of the San Juan rock units are pervasively sheared, faulted and slickensided, obscuring bedding and making it difficult to establish whether contacts are essentially depositional or are major faults. One extreme interpretation regards contacts as basically of primary depositional origin and only slightly modified by later shearing and faulting. The other extreme view questions whether any contacts are depositional and regards the islands as a chaotically complex system of faults. Owing to these unresolved differences, no distinction is made on the map between inferred depositional contacts and faults. It may be noted, however, that an interpretation between these two extremes seems to be most in harmony with structural relations on Orcas and San Juan Islands. This area is characterized by complex, but not chaotic structure in which a once coherent stratigraphy has been cut by low-angle imbricate thrust faults along with large mappable tectonic lenses and plates are complexly interleaved. Displacement along several of the larger thrusts is on the scale of several miles. A detailed interpretation of the structure will be presented elsewhere. The main purpose of this report is to outline the lithology of the major rock units. A discussion of the age, inferred stratigraphic and structural relations of the units together with comment on their origin is also included, as this information is of general interest and is either new or is not available from any other single source.

The stratigraphic units are described in sequence from oldest to youngest. The formational names used here for the major rock units are mostly those of McLellan (1927). Several of his names, notably Leech River, have been abandoned as they include rocks which are of widely differing age or doubtful correlation. Others are redefined and restricted in the light of new data. Only two strictly new formational names (Constitution and Lummi) are proposed and several major lithologic units, originally part of McLellan's Leech River and Orcas Groups, are here left unnamed.

TURTLEBACK COMPLEX

One of the major rock units in the San Juan Islands comprises a complex association of gabbro, quartz diorite and related plutonic igneous rocks and finer grained dike rocks. Rocks of this unit occur most extensively on Blakely, Orcas and Lopez Islands. They are generally resistant to erosion and, in larger outcrops stand up as steep cliffs and prominent hills and ridges. This unit was named the Turtleback Complex by McLellan (1927) for outcrops in the Turtleback Range on Orcas Island and was interpreted as of Jurassic age and intrusive into Paleozoic and Mesozoic strata. Evidence, first recognized in 1958 by myself and Ross Ellis on Orcas Island, indicates, however, that this age assignment is incorrect and demonstrates that the Turtleback Complex is old basement which predates Upper Middle Devonian, the age of the oldest dated fossiliferous beds in the San Juan Islands. Although the primary relations between the Turtleback and other units on Orcas are in part obscured by faulting, a careful study failed to reveal evidence of either intrusive contacts or contact metamorphism. Moreoever, the Turtleback Complex exhibits a general and extensive metamorphic recrystallization of greenschist facies grade. This metamorphism is absent in the Late Paleozoic and Mesozoic beds of the San Juans which show a much lower grade alteration. This sharp contrast in metamorphic grade suggests that both the initial formation of the Turtleback Complex and its later metamorphism predate deposition of Middle Devonian and younger strata. This interpretation is strengthened by the occurrence of cobbles and pebbles of Turtleback material in conglomerates of probable Devonian age on the west side of Orcas Island and by the common occurrence of such conglomerates in strata of Mesozoic age. The Turtleback Complex is clearly older than these conglomerates. Further evidence for the antiquity of the Turtleback Complex is the probable unconformity between this unit and overlying Devonian sandstones and limestones which Danner (1966) has described on O'Neal Island. This contact, although faulted, appears to be essentially an unconformity. Finally, bedded cherts of probable Permian age overlie the Turtleback Complex over wide areas on Orcas Island in what may be an unconformable relationship. The great age of the Turtleback Complex has recently been confirmed by radiometric dating of zircons from two quartz diorites which yielded an age of about 460 million years or Late Ordovician (Mattinson, 1972).

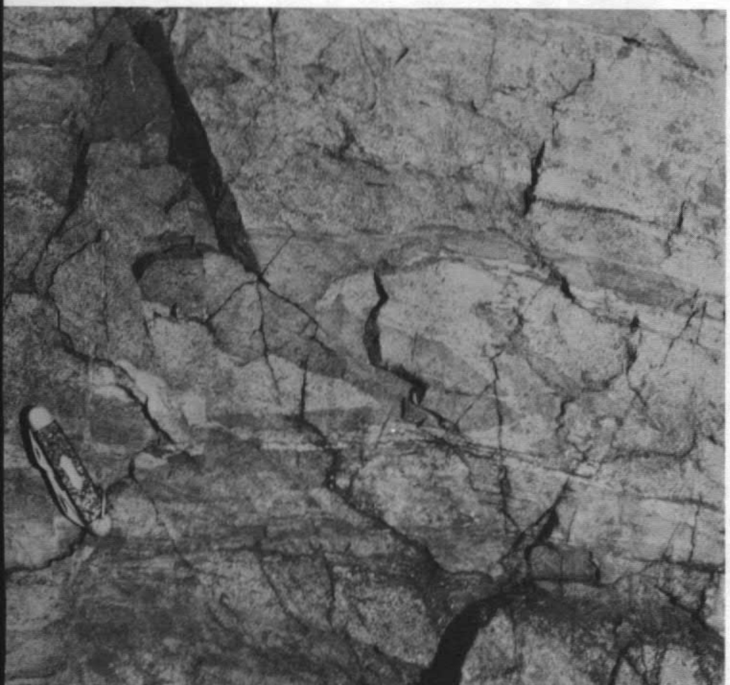


Fig. 1. Layered diorite and gabbro of the Turtleback Complex showing minor folds. Head of East Sound, Orcas Island.

A characteristic feature of the Turtleback Complex is its heterogeneity and the wide variety of different rock types and textures commonly found at individual outcrops. Medium to coarse grained dark igneous rocks, mostly gabbro and diorite and related pegmatites, locally with minor coarse grained black clinopyroxenite, are the most typical rocks of the Turtleback complex, making up perhaps two thirds of the unit. These mafic plutonic rocks commonly occur in close association and at a few localities are interlayered. The close association and textural and mineralogical intergradation of these rocks suggest possible derivation by differentiation of a common mafic parent magma. Medium grained, light colored granitic rocks, chiefly quartz diorite and trondhjemite, are also abundant and appear to make up about a fourth of the basement complex. These quartz diorites and trondhjemites occur both as relatively large uniform bodies, as on the western part of Orcas Island, and as smaller dikes and irregular intrusive bodies which cut more the mafic igneous rocks. It is not known whether the quartz dioritic rocks are the same age as or are genetically related to the gabbros. At many localities the plutonic rocks of the Turtleback Complex are cut by swarms of finer grained and aphanitic dikes ranging from dark basalt, diabase and amphibolite to light green, and grey and tan quartz porphyries of dacitic composition. It is uncertain whether all these dikes belong to the same igneous intrusive cycle as the plutonic rocks or whether they are in part younger and related to later Paleozoic or Mesozoic volcanism. On Orcas Island minor outcrops of serpentinite at the head of Deer Harbor and in the northwest side of upper East Sound have been mapped with the Turtleback.

The rocks of the Turtleback Complex have been subjected to two stages of metamorphism which locally are so intense as to obscure their primary igneous features. The earlier phase of metamorphism is of greenschist facies grade and is characterized by static recrystallization of the primary minerals to albite, epidote, chlorite, and actinolite or hornblende. This metamorphism does not involve Devonian and younger strata and presumably predates their deposition. The Turtleback also shows a later phase of metamorphism characterized by deformation and by the formation of the mineral prehnite, most commonly in veinlets (Vance, 1968). Intense slickensiding, shearing, and microbrecciation locally accompany this phase. This metamorphism involves Upper Paleozoic and Mesozoic rocks and appears to be related to intense Late Mesozoic deformation and thrust faulting.

Plutonic igneous rocks similar to and radiometrically dated as of approximately the same age as the Late Ordovician Turtleback Complex occur at scattered localities in the western Cascade Mountains of northern Washington where they have been termed the Yellow Aster Complex. Misch (1966) and Vance (1974) have interpreted the Turtleback and Yellow Aster as old continental crust, a view supported by the presence of silicic Pre-Cambrian (ca. 1.5 billion years) metamorphic rocks in the Yellow Aster as well as by the abundance of quartz diorite and related silicic plutonic rocks in both units. This view has been questioned by Mattinson and Hopson (1972) and by Brown (1974) who regard the plutonic rocks and associated dikes of the Turtleback and Yellow Aster as part of an ophiolite, that is as thin mafic crust of the type found in the ocean basins. Well-documented ophiolites from other regions occur in the form of pseudostratiform sequences consisting from the base up of: 1) gabbro and related mafic plutonic rocks; 2) swarms of intrusive diabase and basalt dikes; and 3) thick accumulations of basaltic submarine volcanic rocks. These sequences are typically on the order of about 4 km thick and overlie olivine-rich ultramafic rocks and serpentinites of the oceanic upper mantle. The interpretation of the Turtleback Complex as an ophiolite is consistent with the widespread occurrence of ultramafic rocks in the eastern San Juan Islands which could represent oceanic upper mantle and with the abundance of mafic plutonic rocks in the Turtleback. It is weakened however, by the lack of evidence for the existence of the upper volcanic members of the sequence. Moreover quartz-rich granitic rocks, quartz diorite and trondhjemite are abundant in the San Juan and Cascade basement rocks, but are absent or minor in typical ophiolites. If elements of an ophiolite are present in the Turtleback Complex they are probably older than and would appear to be unrelated to the quartz dioritic rocks. I tentatively favor the interpretation that the Turtleback Complex is not an ophiolite, but is essentially continental and that both the mafic and silicic plutonic rocks represent the deep root zone of a magmatic arc and were intruded into still older continental crust represented by the older elements of the Yellow Aster Complex.

GARRISON FORMATION

The rocks here referred to as the Garrison Formation or Garrison Schist were first recognized and named by Danner (1966) at several small outcrops around Garrison Bay on San Juan Island. Danner described them as greenish phyllites and assigned a pre-Devonian age. My field and petrographic studies show that the unit consists of fine grained, low grade schists and crops out extensively on northwestern San Juan Island as a discontinuous sheetlike body. This sheet ranges up to about 400 feet in thickness and has been traced with one major break for about 8 miles along the strike. The schist has been tectonically emplaced along or near the contact between Permian bedded cherts and unconformably overlying Mesozoic conglomerates and siltstones. The attitude of the schistosity conforms roughly to that of the tectonic sheets. Similar rocks crop out at two isolated localities on Orcas Island, but are too small to indicate on the map.

The rock types in the Garrison Schist, in order of decreasing abundance, are greenschist, amphibolite and phyllitic quartzite. These rocks are fine grained, lustrous, sharply foliated schists which tend to be weak and friable. Minor folds and crenulations are locally present and coarse segregations of white vein quartz are common. The greenschists vary considerably in their mineral composition. Common mineral assemblages are albite-chlorite-calcite-muscovite-quartz and albite-epidote-actinolite-chlorite. The amphibolites are fine grained, dark green to black foliated rocks consisting of albite and epidote together with green hornblende showing pronounced lineation. The hornblende in one specimen shows overgrowths of the blue amphibole, crossite. The phyllitic quartzites are dark graphitic rocks consisting of quartz and subordinate muscovite. Minor chlorite may be present and garnet was observed in a single sample. The mineral assemblages of the greenschists and amphibolites indicates metamorphism under different physical conditions within the greenschist facies. The present close association of these rocks of low, but contrasting metamorphic grade appears to reflect major structural displacement within the unit during its emplacement by thrusting.

The parent materials of the Garrison Schist appear to have been mafic volcanic rocks with thin interbeds of impure chert. The primary relation of this unit to the Turtleback Complex is not known. Although the metamorphism of the schist was accompanied by major deformation, while that of the Turtleback Complex was essentially static, it appears significant that their metamorphic grade is the same. It is thus possible that these units were metamorphosed together in pre-Middle Devonian time. Certainly the schist is older than the Constitution Formation (Jurassic?) which locally contains angular clasts of the schist. It is speculated that the volcanic and sedimentary parent materials of the Garrison Schist were laid down unconformably upon eroded basement of the Turtleback Complex. This relation is analogous to that inferred for similar low grade schists of the Easton Formation which overly metaplutonic rocks of the Yellow Aster Complex in the Shuksan thrust sheet in the Cascade Mountains to the east (Misch, 1966; and Vance, 1974). If this interpretation is correct, the Garrison Schist post-dates the Upper Ordovician Turtleback Complex and predates upper Middle Devonian, thus its initial deposition and metamorphism both took place in the time interval Silurian-earlier Devonian (Vance, 1974).

Tectonic emplacement of the Garrison Schist is believed to be synchronous with Late Mesozoic overthrusting in the San Juan Islands. Structurally the schist occupies a position which approximately follows the unconformity between Permian bedded cherts and overlying Mesozoic clastic sediments. The unit appears to have been tectonically inserted into the stratigraphic section as a thin sheet with apparently only minor displacement between the Permian and Mesozoic rocks. During emplacement by faulting the schist was strongly deformed by shearing, slickensiding and fracture.

UPPER PALEOZOIC SEDIMENTARY and VOLCANIC ROCKS

Terminology

McLellan referred sedimentary and volcanic rocks of known and inferred Paleozoic age in the San Juan Islands to the Orcas and Leech River Groups. However, paleontologic studies by Danner and mapping by Vance indicate the need for substantial revision of both the age assignments and terminology of his stratigraphic units. McLellan mapped beds which he believed to be of Devonian and Mississippian age as the Orcas Group. Extensive fossil study by Danner shows that, although Devonian rocks do occur in McLellan's Orcas unit, there is no paleontologic evidence for the presence of Mississippian rocks and that most of the unit is actually of Permian age. I propose that the term Orcas be restricted to the thick sequence of bedded chert and associated submarine volcanic rocks and minor limestones which McLellan states to be the distinctive rock types of the unit and which form the bulk of the Orcas unit as mapped by McLellan.

McLellan assigned a Pennsylvanian-Permian age to clastic sedimentary rocks which in part lie stratigraphically above the cherts of the Orcas Group and placed them in the Leech River Group by a tenuous correlation with unfossiliferous clastic rocks on Vancouver Island. Recent mapping and fossil discoveries, however, show McLellan's Leech River, like his Orcas, to be composite and it seems best to abandon both the name and the correlation. Most of McLellan's Leech River consists of unfossiliferous Mesozoic siltstones and graywackes which unconformably overlie Permian rocks. On Orcas Island pyroclastic rocks now known to be of Early Pennsylvanian age were also included in McLellan's composite Leech River Group.

Devonian

Limestone lenses containing Devonian fossils on the west side of Orcas Island were studied by McLellan and designated as part of his Orcas Group, a unit consisting primarily of a thick sequence of bedded gray cherts. The term Orcas is here restricted to rocks of the chert sequence which are now known to be of Permian age, as it is clear from both McLellan's description and his mapping that this lithology is the principal basis for definition of the unit. The subordinate Devonian rocks included by McLellan within his composite Orcas Group are here excluded from the Orcas and are not here assigned a formal name. Additional fossil discoveries by Danner on Orcas and O'Neal Islands has increased the number of known Devonian localities and has established that these rocks are of late Middle Devonian age. The Devonian of the San Juan Islands is lithologically similar to and of approximately the same age as fossiliferous Devonian strata described by Danner (1966) on the west flank of the North Cascade Mountains.

The limestones of the Devonian have been described in detail by Danner (1966). They occur as lenticular bodies up to 300 feet long and 100 feet wide. Many of the larger lenses have been extensively quarried. The limestones are mostly light gray in color and yield a bituminous odor when freshly broken. Some of the limestone bodies are little recrystallized and fossils, breccia and other primary sedimentary textures are clearly recognizable. Others are partly or entirely recrystallized to coarse grained white or gray aragonite, a dense form of calcium carbonate.

Closely associated with the Devonian limestones are a variety of different clastic sedimentary rocks. Black shales and argillite together with thin-bedded siltstone and sandstone are widespread, and graywacke and conglomerate occur more locally. Volcanic rocks, including andesitic tuff and breccia and rare lavas, are also commonly associated with the limestone. It is probable that these rocks, like the limestones, are also of Devonian age, but the section is extensively faulted and it is uncertain to what extent some of the limestone bodies may have been structurally displaced from their original position in the stratigraphic sequence. Graywacke and conglomerate beds of probable Devonian age described by McLellan and Danner on the west shore of Orcas Island are of interest in that they contain pebbles and cobbles of quartz diorite, diorite and silicic dike rocks derived from erosion of the Turtleback Complex. Clastic sedimentary rocks at two localities on Orcas and Henry Islands are here tentatively assigned a Devonian age on the basis of lithology. Dark brown, fissile calcite-cemented tuffaceous shale and siltstone on northern Orcas Island crop out in a poorly exposed northeast-striking belt about two miles long and 1000 feet wide. At the southwest end of this belt these sediments lie in apparent conformable contact with fossiliferous Devonian limestone. A small outcrop of steeply dipping thin-bedded siltstone and sandstone on northern Henry Island is lithologically similar to Devonian sediments elsewhere in the San Juan Islands. These sedimentary rocks are in contact with diorite and diabase of the Turtleback Complex and crop out along the shore in a narrow strip in probable fault contact with cherts of the Orcas Formation.

Some tentative conclusions about environment of deposition can be made for the Devonian strata. The presence of corals and related fossils of characteristic reef habitat points to marine deposition of the limestones and the associated sediments, probably in shallow seas, although the organic reef debris of the limestones could have accumulated at greater depth after submarine slumping. Contact relations on O'Neal Island suggest a major unconformity between the Devonian and the underlying Ordovician plutonic rocks of the Turtleback Complex. The interpretation that the Turtleback is basement upon which upper Middle Devonian and younger rocks were deposited is supported by the presence of Turtleback detritus in graywackes and conglomerates of probable Devonian age on the west shore of Orcas Island and by the local occurrence in the Devonian sequence of relatively mature quartz-rich siltstones apparently derived from quartz-rich plutonic rocks. The most abundant sediments in the Devonian section are well bedded and sorted marine tuffaceous siltstones and sandstones derived from fine grained fragmental volcanic material. These volcanic sediments are associated with poorly sorted contemporaneous andesitic pyroclastic rocks, especially tuff and breccia. The Devonian beds are here regarded as having been deposited upon a basement of Turtleback in a marine volcanic arc environment. The eruptive products of andesitic volcanoes, possibly including both islands and seamounts, were in part rapidly deposited as unsorted volcanic sediments and were in part reworked by wave and current action and ultimately accumulated as bedded, relatively well-sorted sediments. Locally the Turtleback Complex and related basement rocks were exposed to erosion and contributed clastic debris to the sedimentary sequence. Limestone accumulated locally, probably both as reefs and shallow water limestone banks.

Pennsylvanian

Andesitic fragmental volcanic rocks and related volcanic sediments of Pennsylvanian age occur on both Orcas and Jones Islands. These rocks were designated by McLellan (1927) as part of the Leech River Group. The term is abandoned here, however, as these rocks are very different from the Leech River of Vancouver Island and are probably of different age. No new name is proposed for this unit.

On Orcas Island the Pennsylvanian rocks are exposed in two major outcrop belts. One belt on the west shore is up to a mile wide. The rocks of this zone strike northeast and dip moderately to the southeast. They overlie Middle Devonian with probable disconformity and are in high-angle fault contact with rocks of the Turtleback Complex. The rocks of the other belt crop out along the northeast shore, striking northwest and dipping generally southeast. This belt of Pennsylvanian rocks widens to the northwest reaching a maximum width of about one and a half miles. On northeastern Orcas the unit is intersliced with large tectonic plates of Turtleback along major low-angle thrust faults. The Pennsylvanian beds on Orcas form an arcuate outcrop pattern which roughly defines a large south-plunging syncline. Faulting and folding complicate the structural picture, making it difficult to accurately determine the thickness of the stratigraphic section, but a minimum thickness of about 1,500 to 2,000 feet is probable. The Pennsylvanian on Jones Island is structurally more simple, trending northeast with moderate to steep northwest dips and an exposed thickness of almost 2,000 feet.

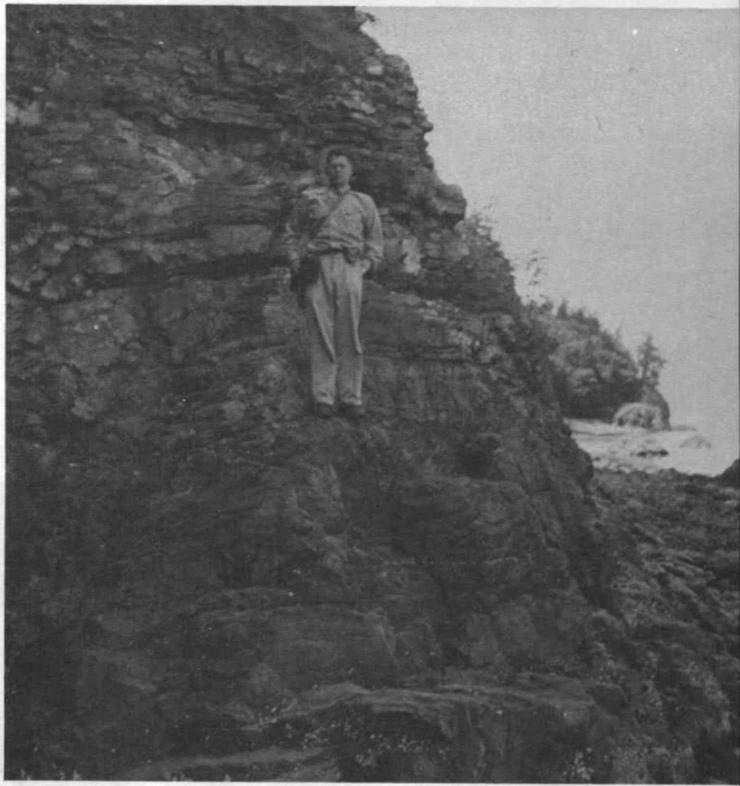


Fig. 3. Bedded Pennsylvanian volcanic breccia and tuff, northeast shore of Orcas Island.

Fig. 2. Unsorted andesitic volcanic breccia, Early Pennsylvanian. Northeast shore of Orcas Island.

The Pennsylvanian unit consists predominantly of andesitic pyroclastic volcanic rocks and volcanic sediments. Limestone beds and lenses, though minor in amount, occur widely in the unit and at several localities contain fossils which establish an Early Pennsylvanian age. Rocks of the same age occur in the northwest Cascade Mountains to the east (Danner, 1966, 1970). In the San Juan Islands the most abundant rocks are unsorted greenish, less commonly gray, tan or reddish tuffs, tuff-breccias and breccias. These occur as thick massive layers showing little evidence of bedding. The angular andesitic fragments are fine grained rocks which display a wide variation in texture. Many fragments are porphyritic revealing small scattered white phenocrysts of plagioclase feldspar, while others are amygdaloidal and are marked by oval gas cavities filled with calcite, quartz, prehnite and other secondary minerals. Microscopic study shows that augite is generally present as small phenocrysts along with the plagioclase. Fragments in the coarse breccias range up to about a foot in diameter. Inter-stratified with these massive rocks are layers of bedded tuff and tuff-breccia a few inches to several feet in thickness. Graded bedding is common. Well-sorted layers of crystal tuff consisting largely of small euhedral plagioclase crystals occur locally. A widespread and characteristic rock type in the unit is dense, highly indurated, dark brown to black siliceous tuff occurring as beds up to several feet thick. Some of these fine grained tuffs contain radiolaria, small spherical siliceous microorganisms. Lavas are rare in the unit, though pillow lava was observed on the northwest side of Jones Island. Minor beds of well sorted shale, siltstone and graywacke, in part carbonaceous, are present in the Pennsylvanian on the northeast side of Orcas Island.

Abundant limestone beds and lenses up to about 300 feet long and 100 feet wide are interbedded in the unit and have been described by Danner (1966). The limestones are typically fine grained and white to gray in color. Fragmental textures, ranging from fine calcareous mud to oolitic, to foraminiferal, and crinoidal limestones and breccias are common types. Locally the limestones are in part or entirely recrystallized to coarse grained aragonite marble. Many of the carbonate rocks yield a strong bituminous odor when freshly broken. Distinctive Lower Pennsylvanian foraminifera, calcareous microfossils, are present in many of the limestones. Danner (1966, 1970) reports similar, but poorly preserved foraminifera in limestone near Roche Harbor on San Juan Island. If his identification of these fossils as Pennsylvanian is correct, the Roche Harbor limestone is stratigraphically out of place. It does not occur in its normal setting with fragmental andesitic volcanic rocks, but is intercalated in a thick sequence of bedded chert and submarine basaltic volcanic rocks, a unit which both stratigraphic position and fossil evidence indicate to be a Permian rather than Pennsylvanian age. It appears that either his age assignment of these fossils is incorrect or the limestone has been faulted into the chert sequence.

At several localities, notably at the head of East Sound and on the southwest part of Orcas Island and on Jones Island, the Pennsylvanian beds are cut by numerous fine grained dikes varying in composition from dacite to andesite and basalt. Some of these dikes may have served as feeders for Pennsylvanian and younger volcanic rocks. Similar dikes are widely present in the Turtleback Complex and are found locally in the Devonian. They are rare in Permian and younger strata in the San Juan Islands.

The andesitic tuffs, breccias and volcanic sediments of the Pennsylvanian closely resemble the products of present day volcanic island arcs such as those of the western Pacific Ocean. The abundance of limestone interbeds in the unit indicates marine deposition. The texture of the pyroclastic rocks and the lack of evidence for a source within the area mapped implies transportation by sedimentary agencies to the final place of deposition in the sea. The volcanoes which supplied the fragmental volcanic debris which makes up the Pennsylvanian may have been seamounts or may have built up above sea level to form islands. Subaerial lava flows which could be interpreted as having formed above sea level have not been recognized in the unit. The general angularity of the fragments points to rapid erosion, transport and deposition, perhaps initiated by slumping on the steep flanks of active volcanoes. The coarser unsorted beds were probably deposited by submarine mudflows, while the tuffs which commonly show graded bedding, were probably transported as fine grained material suspended in turbidity currents. Pennsylvanian volcanic activity resembles and appears to be a resumption or continuation of arc type volcanism initiated in the Middle Devonian. In contrast to the Middle Devonian rocks, quartz-rich sediments derived from the Turtleback Complex or other quartz-rich crustal rocks appear to be rare. As already noted the presence of limestone in the Pennsylvanian sequence demonstrates marine deposition. It is not possible, however to establish the depth of accumulation below sea level because the limestones consist largely of clastic fragmental material which has been transported from its initial shallow water site of origin. The absence of sorting in the volcanic rocks may signify deposition in rather deep water below the reach of wave and current action.

Permian

Introduction. Permian sedimentary and volcanic rocks crop out widely on San Juan, Orcas, and Henry Islands and less extensively on several other islands of the San Juan Group. On western San Juan Island Danner (1966) recognized three units which he considers to be of Permian age and correlates with Permian strata in the west flank of the North Cascades. The lowest unit consists of Middle Permian basaltic submarine volcanic rocks. The middle unit, here referred to as the Orcas Formation and also of Middle Permian age, is largely ribbon chert. The uppermost unit is a thick sequence of siltstone and graywacke here termed the Constitution Formation. As discussed below, the evidence suggests that it is of Mesozoic rather than Permian age.

Volcanic Unit. The lowest and presumably oldest Permian unit on San Juan Island is an unnamed sequence of basaltic pillow lavas, breccias and tuffs with interbeds of ribbon chert and limestone which is exposed over a distance of about two miles along the west coast of the island. McLellan (1927) included this unit in his "Eagle Cliff Porphyrite" which he interpreted as Jurassic intrusive rocks. As elsewhere in the San Juans, however, the "Eagle Cliff Porphyrite" is not intrusive, but consists of the products of submarine volcanic eruptions, and especially of pillow lavas. Moreover, the presence of large fossil foraminifera known as fusilinids in limestones from this unit indicate a Middle Permian age. The base of this volcanic sequence is not exposed. Mapping by Danner in the southern part of the unit suggests that the beds are structurally repeated by a series of tight east-west-trending folds. Farther north these strata strike northwesterly parallel to the regional trend on western San Juan Island. The unit is apparently quite thick, but owing to structural complexity including folding and faulting it is not possible to make an accurate estimate of its thickness. This volcanic unit has not been recognized elsewhere in the San Juan Islands.

The principal rock types in the volcanic unit are pillow lavas, breccias and tuffs. These rocks range from green to red in color and are in part porphyritic containing phenocrysts of plagioclase feldspar. Microscopic study and preliminary chemical data suggest that the rocks are basaltic andesite. The pillow lavas are submarine lava flows made up of close-packed aggregates of "pillows", bulbous ellipsoidal masses of lava as much as two feet in diameter. The pillows commonly show concentric zones of gas cavities near their margins and may be interconnected. The pyroclastic rocks grade from coarse breccias with fragments up to about a foot in diameter to tuff-breccias and fine grained tuffs. Broken pillows are common in the coarser breccias. The angular fragments which make up the pyroclastic volcanic rocks probably formed by shattering of submarine lava during rapid chilling in contact with sea water and by violent expansion of gasses. The abundance of fragmental volcanic rocks suggests formation in relatively shallow water. To a lesser extent fracturing may have occurred during transport of volcanic debris as submarine mudflows. The vents through which the Permian volcanic rocks were erupted presumably lie within or near the present outcrop area of the unit. The andesitic island arc type volcanism which characterized the Devonian and Pennsylvanian had terminated before Permian time.

Both limestone and chert are present as interbeds in the volcanic unit. The limestones occur mostly as small lenses, but Danner mapped a large bed about 1,500 feet long and 300 feet wide. Limestone also appears as angular fragments up to several feet in diameter in the volcanic breccias into which it was apparently mixed during submarine slumping. The limestones are fine grained light gray rocks some of which contain well preserved fossils, chiefly fusilinids and calcareous algae. These fossils indicate shallow water deposition, probably on reefs fringing oceanic volcanic islands or on shallow offshore carbonate banks.

Gray, red and green ribbon cherts are present in the volcanic unit as interbeds a few feet to perhaps a hundred feet thick. These are regularly bedded cherts consisting of layers about one inch thick separated by thin shaly partings. The cherts consist in part of the siliceous remains of marine microorganisms known as radiolaria. The association of the cherts with shallow water limestones suggests that these rocks are also of shallow marine origin. Coarse grained sandstones made up entirely of small angular chert fragments occur locally in the volcanic unit and presumably are the result of breakup of the cherts by bottom currents or wave action shortly after deposition.

Orcas Formation. On western San Juan Island the Middle Permian volcanic unit is overlain by a thick sequence of ribbon chert with minor intercalations of basaltic tuff and pillow lava and scattered limestone beds. This distinctive chert unit makes up most of the composite "Orcas Group" of McLellan. The name Orcas Formation or Orcas Chert is retained here and restricted to these rocks. This unit appears to be as much as 2,500 feet thick on western San Juan Island and 1,200 feet thick on Orcas. The Orcas cherts are gray ribbon cherts consisting of layers about an inch thick separated by thin shaly partings. The layers commonly pinch and swell and many can be seen to terminate laterally. Radiolaria are conspicuous in thin sections of the more impure cherts. Small white quartz veinlets nearly at right angles to the bedding are characteristic of the cherts. Rare beds of intraformational chert breccias and coarse chert sandstone occur in the unit indicating the action of currents on the unconsolidated sediments shortly after deposition. The cherts are well bedded rocks whose dip and strike. though irregular in detail and locally modified by tight minor folds, is relatively uniform over wide areas and defines a series of southeast-plunging open folds. Among these folds are: the large syncline on San Juan Island; the syncline occupying the peninsula between East and West Sound on Orcas Island; and the anticline which parallels the axis of East Sound on Orcas. Small faults, both subparallel to and at

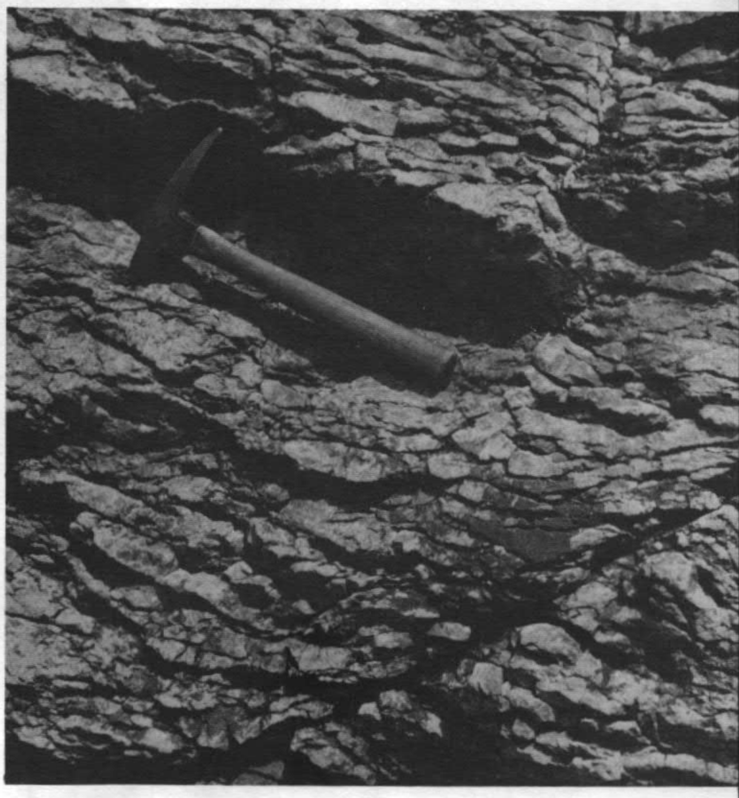


Fig. 4. Ribbon chert, Middle Permian Orcas Formation, East Sound, Orcas Island. The chert layers are lenticular and of variable thickness.

Fig. 5. Even-bedded ribbon chert of the Orcas Formation. East Sound Orcas Island.

high angles to the bedding, are additional characteristic minor structures in the Orcas cherts. While the cherts consist primarily of silica and are very hard rocks, they fracture readily along the bedding, on minor faults and along small quartz veinlets across the bedding and thus are easily eroded and tend to form low, subdued topography.

Basaltic rocks, chiefly tuff, rarely breccia or pillow lava, are sporadically interbedded with the chert, but generally make up less than 25 per cent of the unit. The fine grained tuffs appear to have been derived from a relatively distant volcanic source. Limestone interbeds in the Orcas Formation are lenticular and range from a few inches to about a hundred feet in thickness. The larger limestone bodies have been extensively quarried. Most of the limestone beds in the unit are partially or completely recrystallized to coarse grained aragonite marble (Vance, 1968). The absence of land-derived clastic sedimentary interbeds in the Orcas Formation indicates that it was deposited in a pelagic or open ocean environment remote from any large landmass. Accumulation of this unit in the deep sea environment, however, appears to be excluded by the abundance of shallow water limestone.

Danner (1966) reports the occurrence of Middle Permian fusulinids in limestones interbedded in cherts and volcanic rocks of the Orcas Formation at three localities on San Juan Island. These fossils indicate that the Orcas is about the same age as the underlying volcanic unit. The contact between these two units on San Juan Island is not exposed. The contact may be depositional, but differences in structural style between the two units leave open the possibility that it is a low-angle thrust fault, in which case the volcanic unit and the Orcas Formation may be laterally equivalent. As noted above, Danner (1966) has described poorly preserved fossils of possible Pennsylvanian age from limestones associated with a thick unit of bedded chert and volcanic rocks in the Roche Harbor area on San Juan Island. Because this unit is identical in rock type to the Orcas and because cherts are absent in proven Pennsylvanian rocks elsewhere in the San Juan Islands, it would appear that either the Pennsylvanian age assigned to the fossils is incorrect, or, less-probably, that the limestone was faulted into the chert unit.

Fossils have not been found in the Orcas Formation on Orcas Island, but litholithic correlation with the unit on San Juan Island suggests that it is also of Middle Permian age. On Orcas, and locally on northern San Juan Island, the volcanic unit of western San Juan Island is absent and the Orcas cherts overlie Ordovician basement rocks of the Turtleback Complex. Parallelism of the bedding of the cherts with the contact suggests a possible unconformity. However, if this interpretation is correct, the absence of clastic sedimentary rocks at the base of the chert section is anomalous and it is possible that the contact is a fault rather than an unconformity. Small faults subparallel to the bedding are widely present in the chert unit and the contact itself is sheared and slickensided. It is uncertain, however, whether movement along the contact reflects only minor displacement involving shearing-off along an unconformity or truly large scale faulting. The Orcas Formation is overlain on San Juan, Shaw and Orcas Islands by a thick unit of sheared siltstones and graywackes which are probably of Mesozoic age and are here referred to as the Constitution Formation. As discussed below, the contact of the Orcas and Constitution units is believed to be a major unconformity.

Fig. 6. Small overturned fold in cherts of the Orcas Formation, East Sound, Orcas Island.

Other Permian Rocks. Fossil fusilinids discovered by Danner (1966) establish the presence of Permian rocks both older and younger than the Orcas Formation on Orcas Island. These Early and Late Permian rocks have not been recognized elsewhere in the San Juan Islands, although deposits of this age occur on the mainland on the west flank of the Cascade Mountains. Early Permian fusilinids have been found in two limestone bodies on Double Hill just north of East Sound. These limestones are associated with poorly exposed volcanic rocks and graywackes which appear to be in high-angle fault contact with rocks of the Turtleback Complex on the south and with Pennsylvanian volcanic rocks and limestone on the north. These rocks are the oldest Permian yet recognized in the San Juan Islands. They are lithologically unlike the Orcas and appear to predate it entirely. To simplify the map this local occurrence of Early Permian rocks is shown as Orcas.

Late Permian fusilinids are reported by Danner from limestones in the Judd Cove area near the head of East Sound and from one locality on the northwest shore of Orcas. (These rocks are shown on the map as Orcas). The limestone beds of Judd Cove occur in a sequence of green and red marine tuffs, breccias, pillow lavas, ribbon chert, chert breccia and chert sandstone. These Late Permian rocks occur as a series of fault slices in tectonic contact with diorite, diabase and serpentinite of the Turtleback Complex. This Late Permian unit differs from the Orcas Formation in the abundance of sedimentary chert breccias and in that volcanic rocks greatly predominate over chert. Similar fossiliferous Upper Permian rocks crop out locally on the northwest shore of Orcas Island. Their contact with Devonian or Pennsylvanian volcanic rocks farther inland is not exposed. The relations of the Upper Permian rocks to the Orcas Formation are not known as the two units are nowhere in contact. Instead, the Orcas is unconformably overlain by clastic rocks of probable Mesozoic age.

MESOZOIC

Introduction

Understanding of the Mesozoic stratigraphy of the San Juan Islands is hampered by the absence of fossils in several of the key units, leading to uncertainty as to their age, as well as by controversy as to their structural relations and the possibility that rather different rock units may be of the same age. Much of the following discussion, therefore, is interpretation and is subject to revision in the light of new evidence. Among the rock units recognized as Mesozoic by McLellan on the basis of their fossils are the Upper Triassic Haro, the Lower Cretaceous Spieden and the Upper Cretaceous Nanaimo Formations. Two additional units, here assigned to the Mesozoic and termed the Constitution and Lummi Formations, are parts of McLellan's original Leech River Group.

The Mesozoic units differ significantly from the Paleozoic in their rock types. The Mesozoic consists largely of clastic sedimentary rocks, notably shale, siltstone and graywacke. Although volcanic debris has contributed significantly to these sediments, this material tends to be better bedded, finer grained and better sorted than the Paleozoic volcanic sediments reflecting extensive transport and reworking by sedimentary agencies. In addition, certain of the Mesozoic units are rich in detrital quartz and plagioclase feldspar derived from a granitic source terrane. In contrast to the Paleozoic rocks, limestone is rare and ribbon cherts are absent or minor in the Mesozoic units.

Haro Formation

The oldest proven Mesozoic rocks in the San Juan Islands are Upper Triassic volcanic sediments exposed in a small area around Davison Head on the north end of San Juan Island. These rocks were described by McLellan who named them the Haro Formation and assigned them an Upper Triassic age based on the occurrence of the fossil *Halobia*, a distinctive thin-shelled swimming clam. These fossils occur on the main part of San Juan Island opposite Davison Head in thin impure limestone layers interbedded with tuffaceous shale and coarse volcanic sandstone. Davison Head itself consists of well bedded clastic sedimentary rocks, presumably also of Upper Triassic age. These sediments are largely reworked andesitic and dacitic pyroclastic volcanic material. The principal rock types are: fine grained tuffaceous shale; tuffaceous sandstone made up of plagioclase crystals and small fragments of volcanic rocks; and conglomerates and breccias containing boulders of porphyritic andesite and dacite up to two or three feet in diameter. These beds range from a few inches to about ten feet in thickness. Graded bedding is present locally. Limestone fragments are present in some of the conglomerates. The composition, bedding features and texture of the Haro suggests that these volcanic sediments were derived from a nearby active volcanic source and were deposited in relatively shallow seas, probably in a volcanic island arc environment.

Structural trends in the Haro are approximately E-W. Dips are generally vertical to steep south. Several tight minor folds were observed and the possible existence of larger folds is indicated by abrupt changes in strike. The thickness of the unit is not known owing to incomplete exposure and the likelihood of structural repetition. The Permian Orcas Formation crops out just south of the Haro. The contact of those two units is not exposed, but is probably a major south-dipping thrust fault. Unlike the Permian and Mesozoic rocks south of this fault which are highly sheared and show low grade metamorphic recrystallization, the Haro sediments are remarkably fresh and unaltered. The Haro is the only demonstrated Late Triassic in the San Juan Islands and in western Washington, although fine grained clastic sediments, in part volcanic, of the Cultus Formation in the Cascade Mountains of southern British Columbia are of the same age. Neither the initial extent of the Haro nor its stratigraphic relations to older or younger units is known.

Constitution Formation

The greater part of McLellan's Leech River Group consists of unfossiliferous siltstones and graywackes which stratigraphically overlie the Permian Orcas Formation. As McLellan's correlation of this unit with the Leech River of Vancouver Island is doubtful and because stratigraphic evidence indicates that it is Mesozoic and not Upper Paleozoic, the name Leech River is abandoned here. The clastic sedimentary rocks which overlie the Orcas can be divided into two units of formational rank. The stratigraphically lower unit, made up chiefly of massive sheared siltstones, is named the Constitution for exposures on Mt. Constitution on Orcas Island. The upper unit, named the Lummi Formation for Lummi Island in the easternmost San Juan Islands, consists of well stratified shale and graywacke with locally interbedded pillow lavas and tuffs.

McLellan and Danner both consider the cherts of the Orcas to be gradational and conformable with the siltstones of the overlying Constitution Formation, an interpretation based on the apparent interbedding of cherts with siltstones. Detailed mapping, however, indicates that the Constitution is regionally unconformable on the Orcas and that most of the supposed interbedding of chert and siltstone is the result of repetition by imbricate thrust faulting, a relation well displayed on Orcas Island. At some localities, as on western San Juan Island for example, beds of ribbon chert up to a few tens of feet in thickness are indeed present in the lower part of the siltstone sequence, but these cherts are here considered part of the Constitution Formation rather than the Orcas.

The presence of an unconformity at the base of the Constitution is indicated by several field relations. First, Late Permian rocks, such as those found at Judd Cove on Orcas Island, are not present in the stratigraphic section between the Middle Permian Orcas and the overlying Constitution Formation, In addition, on Orcas Island the Orcas Chert shows a systematic southeastward thinning which appears to be the result of warping, uplift, and erosional thinning prior to deposition of the Constitution. This interpretation is reinforced by the local presence at the base of the Constitution Formation on Orcas Island (at the southeast end of Cascade Lake and at the small bay just east of the town of Orcas) of congolomerates containing well rounded pebbles of both Turtleback and Orcas rocks and by several outcrops where the Constitution overlies more steeply dipping truncated Orcas cherts. Moreover, on northwestern San Juan Island beds of basal conglomerate as much as 100 feet thick occur widely at the contact of the Orcas and the Constitution. Conglomerate outcrops in the Garrison Bay area on San Juan Island were correlated by Danner (1966) with possible Devonian conglomerate on western Orcas Island. Field relations inland and south of Garrison Bay, however, clearly reveal that the conglomerates lie at the base of the Constitution and above the Orcas. The larger clasts in the conglomerates are mostly of pebble size, but cobbles eight inches or more in diameter are common. As on Orcas Island the pebbles are chiefly Turtleback (silicic dike rocks, quartz diorite and diorite) and Orcas (chert, basalt and limestone) rock types. Clasts of Garrison Schist occur in some outcrops.

Danner considered the Constitution to be unconformable on the underlying Orcas Formation and assigned a Permian age to both units. The unconformity at the base of the Constitution, however, indicates significant warping, uplift and erosion before deposition of the Constitution. Although fossils have not been found in the Constitution Formation and the time value of the unconformity is not known, the apparent regional absence of latest Permian and Lower and Middle Triassic deposits in this part of the western Cordillera makes it probable that the Constitution Formation is Late Triassic or younger. Certainly the thick monotonous sequence of siltstone, graywacke and shale which makes up the Constitution and Lummi Formations is unlike any known Paleozoic unit in northwest Washington, but rather is to be correlated with regionally developed Mesozoic clastic rocks. Because the Constitution and Lummi units differ markedly from the Upper Triassic Haro Formation it appears likely that they are of Jurassic or Early Cretaceous age.

The Constitution Formation consists chiefly of brownish massive to slaty sheared siltstone with less abundant gray-green volcanic graywacke. Conglomerate is present at some places at the base of the unit. Thin beds of ribbon chert occur locally near the base of the unit and more rarely higher in the stratigraphic section. Greenish tuffs and tuff-breccias, light-colored lithic sandstones are also present in the unit.

The Constitution Formation is highly deformed and at many places includes tectonically intersliced bodies of other rock units. On Orcas many of these have been mapped in detail. In those areas thus far only examined in reconnaissance small outcrops of these structurally exotic rocks have been mapped as Constitution. On Griffin Bay on southeastern San Juan Island, for instance, local outcrops of pillow lava and red inter-pillow chert which are probably correlative with Whetten's volcanic unit on Lopez Island are not differentiated from Constitution on the map.

The Constitution Formation is highly resistant to erosion, unlike the weak underlying Orcas cherts, and finds topographic expression as bluffs and asymmetrical hills rounded and scoured by glacial action.

The Constitution has experienced intense internal deformation and is characteristically sheared, veined and slickensided. This, together with the lack of distinctive marker beds in the rather uniform sequence have precluded any stratigraphic subdivision of the unit. Deformation was accompanied by low grade alteration and widespread development of white veinlets of the metamorphic mineral prehnite (Vance, 1968). Bedding is seldom recognizable in outcrop, although fine-scale sedimentary lamination and graded bedding are conspicuous in thin sections of many of the siltstones. In the absence of more complete structural data and owing to the probability of repetition by faulting and folding, the thickness of the unit is uncertain. On San Juan and Orcas Islands, however, the apparent thickness exceeds 10,000 feet.

The finer grained sediments of the Constitution consist principally of clay minerals and quartz and plagioclase silt. Granitic crustal rocks contributed significantly to the Constitution Formation in contrast to the Paleozoic clastic rocks which are largely of volcanic derivation. Silt- to sand-sized fragments of andesitic volcanic rocks and volcanic plagioclase are present in some of the siltstones and are abundant in the graywackes. These volcanic graywackes and the associated tuffs reflect contemporaneous andesitic volcanism.

The fine grain size of most of the Constitution Formation suggests deep water sedimentation, possibly from sediment-laden turbidity currents. These may be deep-sea turbidites deposited from density currents set up by slumping of unconsolidated sediments on the continental slope, an origin well documented for modern day deposits which are accumulating off the continental margins.

This simple picture of deep water sedimentation is complicated by the unconformity below the Constitution and by the local presence of conglomerates at the base of the unit. It seems doubtful that submarine currents are sufficiently vigorous to produce an erosional unconformity of this magnitude. Instead, the erosional beveling of the Orcas and Turtleback units below the Constitution and the presence of coarse clastic sediments in the basal Constitution suggest erosion and deposition at or near the earth's surface. If, as seems probable, the conglomerates are shallow water deposits, then the change to finer grained sediments up-section must reflect rapid subsidence during the early stages of accumulation of the unit.

Lummi Formation

A distinctive unit of well stratified graywackes, shales and siltstones crops out widely in the eastern San Juan Islands. This unit, originally included by McLellan in the Leech River Group, is here referred to as the Lummi Formation for excellent exposures on Lummi Island just east of the map area. Rocks correlated here with this unit form a broad arcuate outcrop belt extending from northern Whidbey Island through eastern Fidalgo and Guemes Islands to Sinclair and Lummi Islands then west to Cypress, Obstruction and southeastern Orcas Islands and finally south to southeastern San Juan Island and Lopez. In the southeastern San Juans John Whetten refers to those rocks as "flysch" and finds them to be part of a chaotic and faulted structural complex or "melange". Farther north this unit is less faulted and is coherent structurally. The unit appears to be at least 6,000 feet thick on southern Lummi Island and more than 3,000 feet thick on southeastern Orcas.

The Lummi differs from the Constitution in its generally coarser grain size and in the abundance of graywackes and in that it is much less intensely sheared and faulted. The Lummi Formation overlies the Constitution on southeastern Orcas Island. The contact truncates structures in the Constitution and is probably a thrust fault. The broad similarity of rocks types making up the Constitution and Lummi Formations suggests however, that the two

Fig. 7. Graded graywacke beds of the Lummi Formation, Obstruction Pass, Orcas Island.

units were originally part of a single conformable sequence. During deformation the massive and competent graywackes of the Lummi sheared off the underlying Constitution Formation moving independently as a thrust sheet.

The Lummi is younger than the Constitution and is probably of Early Cretaceous age. On Fidalgo Island Mulcahey (1975) reports the discovery of a fossil clam of probable Cretaceous age from the Lummi. On Fidalgo the Lummi sediments appear to predate andesitic volcanic rocks and tuffaceous sediments of probable Upper Cretaceous age. This age assignment is consistent with the similarity of the Lummi to the Late Jurassic-Early Cretaceous Nooksack Formation of the Mt. Baker area (Misch, 1966).

The Lummi Formation is a rather uniform sequence of interbedded graywacke, shale and siltstone turbidites. The graywackes are dark gray to brown sandstones occurring as massive beds between about one foot and a few tens of feet thick. These beds are commonly graded from coarse material at the base to siltstone or shale at the top. Graywacke grit and breccia consisting of small angular fragments of gray chert and chips and plates of black shale are common at the base of the graded beds. Graywackes containing scattered rounded pebbles, chiefly volcanic rocks and chert up to two or three inches in diameter, together with angular shale chips are less common. A conglomerate from the Lummi of Orcas Island contains lithic clasts of metamorphic prehnite and pumpellyite. The Lummi graywackes are rich in angular sandsized particles of andesitic volcanic rocks. They also contain a major component of detrital clastic quartz derived from granitic source rocks. The presence of epidote as a characteristic minor accessory mineral suggests that metamorphosed plutonic rocks of the Turbleback Complex may have contributed to the sediments. The shales and siltstones are

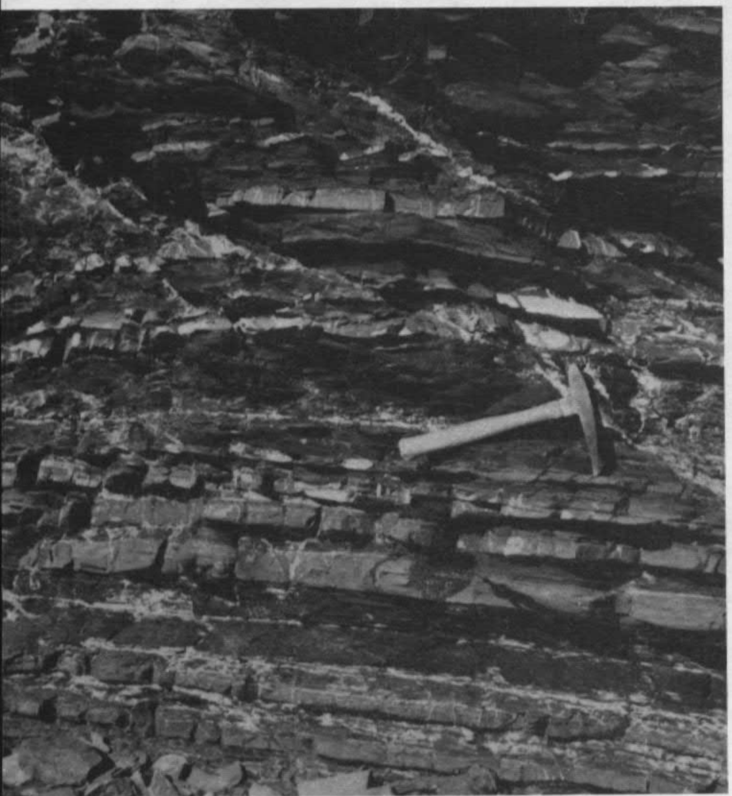


Fig. 8. Interbedded siltstone and shale broken by small faults. Lummi Formation, Obstruction Pass, Orcas Island.

black to gray in color and commonly show a thin sedimentary lamination.

On northern Cypress Island and the adjacent Cone Islands just east of the map area green pillow lavas are associated with and may in part be interbedded with the Lummi sediments. Turbidites and pillow lavas are also associated on Lopez Island, but these rocks are highly faulted and it is uncertain whether these rocks belong to the same stratigraphic unit.

Like the underlying Constitution Formation, the Lummi sediments are here regarded as turbidites, sediments deposited from the suspended load of submarine density currents. The shale chips common in the coarser sediments were eroded from sea floor mud and churned up into the turbidity currents as they swept across the ocean bottom. With decrease in velocity these currents dropped their load of sediment and the coarse material settled out first, giving rise to the size grading of the beds. The Lummi sediments, on average, are coarser grained than the Constitution and presumably were deposited closer to their source. They were probably deposited in deep water off the continental margin, possibly in a submarine fan. The abundance of andesitic volcanic fragments in the graywackes suggests the existence of an active volcanic arc in the continental source area.

In the northeastern San Juan Islands the Lummi beds form a series of fairly broad folds. This relatively simple structural style is complicated by the local presence of tight minor folds, especially in parts of the section consisting of thick shale beds.

Spieden Formation

Spieden Island, situated just north of San Juan Island, consists of Early Cretaceous sedimentary rocks. The Spieden beds trend WNW parallel to the length of the island and dip steeply to the south. The unit is at least 2,000 feet thick. Neither its base or top is exposed. Conglomerates consisting of well rounded, pebble sized clasts make up most of the unit. On the steep north side of the island dark siltstones and shales form the lowest part of the exposed section. These finer grained beds are locally involved in tight minor folds. The Spieden sediments consist almost entirely of andesitic volcanic debris. Pebbles in the conglomerates are fine grained andesite, while the silt and sand size material of the finer grained sediments is largely volcanic plagioclase and tiny fragments of andesite. Calcite cement is common.

Fossil clams and ammonites occur in the siltstones at Spieden Bluff on the north shore of Spieden Island and demonstrate an Early Cretaceous age for the unit. The Spieden is thus the same age as the younger part of the Nooksack Formation (Misch, 1966) of the Cascade Mountains and may be the same age as the Lummi Formation of the eastern San Juan Islands. The Spieden Formation, however, consists largely of andesitic conglomerates and differs from the Lummi turbidites in which graywacke and siltstone predominate and in which clastic quartz is abundant. The Spieden conglomerates are fairly well sorted and were probably deposited in relatively shallow water near their volcanic source. The Lummi and Spieden Formations appear to have accumulated in different depositional environments. If the two units are the same age, as suggested here, their sites of deposition were apparently quite far apart. The present proximity of these two units may be the result of thrust faulting. This interpretation is supported by the fact that the Spieden Formation, in contrast to the Constitution and Lummi units, shows little indication of metamorphic recrystallization. The abrupt contrast between the unmetamorphosed Spieden and Haro and the adjacent sheared and highly altered Orcas and Constitution units suggests the presence of a major fault separating metamorphic and nonmetamorphic terranes on northern San Juan Island.

Nanaimo Group

Introduction. The small northern islands of the San Juan Group consist of folded marine and continental sedimentary rocks, including sandstone, shale, siltstone and conglomerate. On the basis of rock type and fossils McLellan correlated these beds with the Upper Cretaceous Nanaimo Group (Usher, 1952; Muller and Jeletsky, 1970) of Vancouver Island and the Canadian Gulf Islands, McLellan's correlation with the Nanaimo is followed here for the rocks of Stuart, Waldron, and Orcas Island and southernmost Sucia Island. However the thick continental sandstones which make up most of Sucia and the small islands Patos, Matia, Clark and Barnes differ significantly from the typical Nanaimo and are here tentatively correlated with the lithologically similar Chuckanut Formation of Early Cenozoic age which is widely exposed in the Bellingham area just east of the San Juans. Discussion of the Nanaimo here is confined to a summary of the rock types and structure of the Nanaimo as developed on the major islands and to comments on the depositional environment and source of the sediments.

Orcas Island. On Orcas Island the Nanaimo is exposed in a series of outcrops along the north shore. The present summary of the geology of the Orcas Nanaimo is based on work done on the University of Washington Geology field courses and on Peter Ward's non-thesis M.S. study of the stratigraphy and paleontology (1973).

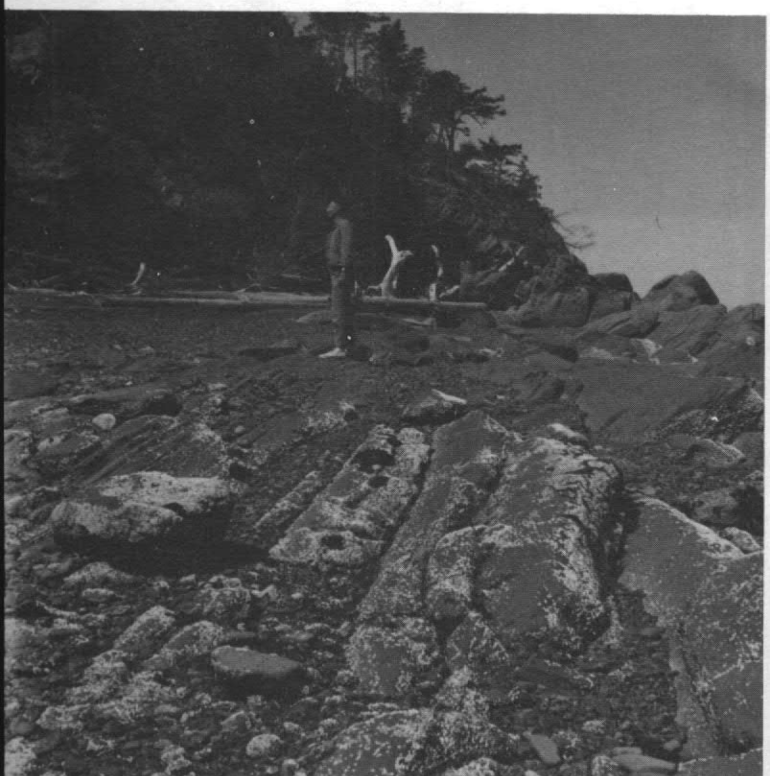


Fig. 9. Well bedded sandstones of the Late Cretaceous Nanaimo Group exposed in a wave-cut beach, north shore of Orcas Island.

Ward measured a stratigraphic section of Nanaimo approximately 1625 feet thick on Orcas. The oldest exposed member of the Nanaimo consists of about 115 feet of massive olive gray sandstone with local pebble conglomerate layers. This is overlain by about 925 feet of fossiliferous laminated siltstone and shale with local interbeds of massive gray to tan sandstone. This member grades into sandstone at the top. The next unit is a distinctive conglomerate about 100 feet thick. The conglomerate is coarse at the base, with subrounded to rounded boulders in excess of a foot in diameter, and grades upward into interbedded pebble conglomerate and sandstone at the top. The principal rock types in the conglomerate are aphanitic and porphyritic rocks, gabbros, diorite and quartz diorites derived from the Turtleback Complex and chert, chiefly gray chert of the Orcas Formation but including occasional conspicuous pebbles and cobbles of red chert. The conglomerate is overlain by about 485 feet of shale and siltstone with beds of sandstone and pebble conglomerate in its lower part. Fossil wood and leaves are common in this member. Ward has found fossil clams and ammonites in the beds both below and above the conglomerate member.

The Nanaimo strikes generally WNW on Orcas. Structural repetition of the congomerate member defines a major syncline between Pt. Doughty and Freeman Island and a major anticline between Freeman Island and West Beach. The contact of the generally south-dipping Nanaimo with older rocks farther south on Orcas is covered by Quaternary deposits, but is inferred to be a fault.

Waldron Island. Nanaimo beds are widely exposed on the southeastern part of Waldron Island and crop out at scattered localities on the north shore. The principal structure in the Nanaimo of Waldron Island is a broad shallow northeast-trending syncline on the eastern part of the island.

Ward measured approximately 2270 feet of Nanaimo strata on Waldron. The lowest exposed member consists of about 60 feet of massive sandstone. This is overlain by 140 feet of pebble conglomerate and interbedded sandstone. This is followed by about 1210 feet of sandstone, locally cross-bedded, with interbedded conglomerate and with a distinctive 100 foot bed of white to gray light gray sandstone near the top. The next unit consists of 500 feet of cobble and boulder conglomerate. Aphanitic and porphyritic dike rocks, Turtleback plutonic rocks and chert, including minor red chert, are characteristic of both this conglomerate and of the thinner finer grained conglomerate member lower in the Waldron section. It is probable that one of these conglomerates is equivalent to the lithologically similar coarse 100 foot conglomerate on Orcas Island. The youngest exposed Nanaimo on Waldron consists of about 300 feet of gray sandstone with interbeds of pebble conglomerate and with interbeds of siltstone at the top. Fossil snails and ammonites occur in this upper unit.

Stuart Island. Nanaimo strata make up most of Stuart Island and the smaller islands to the east. Structurally the island consists of two major tight WNW-trending folds, a syncline on the south and an anticline on the north.

Phifer, in a University of Washington senior thesis (1955), measured approximately 3,700 feet of Nanaimo beds on Stuart Island and subdivided the unit into three members. The oldest member is exposed in the core of the anticline and consists of about 2460 feet of strata, chiefly thin flaggy layers of rhythmically bedded sandstone, siltstone and shale. Subordinate beds of massive gray sandstone, mostly less than 100 feet thick, and conglomerate beds up to a few tens of feet thick are also present. The thin-bedded sediments of this unit are locally deformed into a series of tight minor folds. This lower member is overlain by about 1000 feet of conglomerate with lenticular interbeds of cross-bedded coarse gray sandstone. The conglomerates consist of well rounded clasts, mostly of pebble to cobble size but locally coarser. Aphanitic and porphyritic dike and volcanic rocks predominate among the clasts, but pebbles of chert, siltstone and plutonic igneous rocks are also present. This conglomerate member may be equivalent to a thick conglomerate in the upper Nanaimo of the Gulf Islands to the west. About 240 feet of gray sandstone with local interbeds of shale and minor conglomerate are the stratigraphically youngest beds exposed. On the west side of the island fossil clams, brachiopods and ammonites occur in this unit.

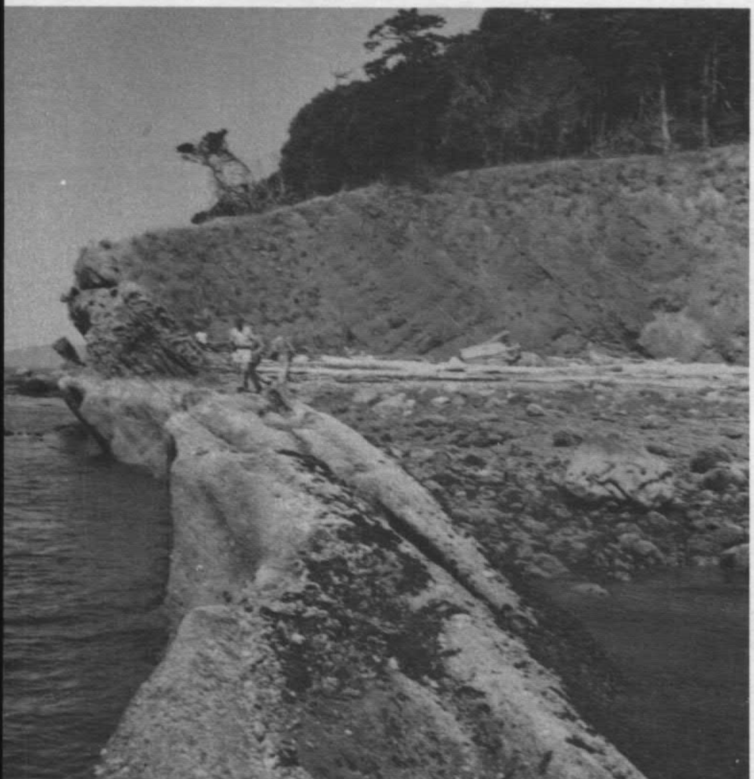


Fig. 10. Conglomerate bed overlain by sandstone and siltstone. Nanaimo Group, Fossil Bay, Sucia Island.

Sucia Island. The sedimentary rocks of Sucia Island have been folded into a tight SSE-plunging syncline, forming a complex horseshoe-like structure open to the east. The Sucia beds are conveniently subdivided into two major structurally concordant units. The older unit consists largely of gray fossiliferous siltstones and is exposed along the southern finger of the island and on Little Sucia Island on the south limb of the syncline. The remainder of the island is a thick younger unit consisting largely of light-weathering cross-bedded sandstones and associated conglomerates. McLellan and later workers have regarded both units as belonging to the Nanaimo Group. The sandstone unit, however, differs both in thickness and lithology from the type Nanaimo. Because it shows greater similarity to the Chuckanut Formation on the mainland to the southeast than to the Nanaimo, it is here tentatively correlated with the Chuckanut.

The oldest Nanaimo on Sucia is a lenticular bed of coarse conglomerate about 50 feet thick which is exposed on the southernmost point of the island at the entrance to Fossil Bay. The south limb of the Sucia syncline apparently continues to Parker Reef about one mile south of Sucia suggesting that as much as several thousand feet of Nanaimo strata may underly the conglomerate. The conglomerate is unique in the Nanaimo of the San Juan Islands in that it is composed of subangular to subrounded clasts of white vein quartz, black phyllite and greenschist up to about 3 feet in diameter. These distinctive rocks were derived from the Easton Schist (Darrington phyllite and Shuksan greenschist). The nearest present exposures of these low grade metamorphic rocks crop out north and east of Burlington in the lower Skagit River Valley on the mainland to the southeast. Gray sandstones interbedded with and overlying the conglomerate contain abundant detrital grains of phyllite, quartz, albite and epidote together with actinolite, hornblende and minor blue amphibole. The coarseness and angularity of the conglomerate debris suggest a nearby source probably now lying beneath the sea to the east.

The conglomerate grades rapidly upward into a unit of grayish siltstone and shale, about 700 feet thick. This siltstone unit is richly fossiliferous, containing abundant shells of clams, ammonites, snails and belemnites, as well as foraminifera. Study of the microfossils (Breitsprecher, 1962) and the megafossils (Ward, 1973) suggests correlation with the Cedar District Formation of the Nanaimo of the Canadian Gulf Islands.

Other Observations On the Nanaimo. The Nanaimo Group consists of clastic sedimentary rocks ranging from shale to siltstone, sandstone and coarse conglomerate. These sediments contain abundant quartz and feldspar implying a major contribution of detritus from quartz-rich granitic and metamorphic source rocks. The coarse clasts of Turtleback plutonic rocks and of Orcas cherts found in the conglomerates of Orcas and Waldron Islands were derived from a nearby source, probably from the south. It may be noted that interbeds of contemporaneous volcanic rocks and volcanic sediments are lacking in the Nanaimo thus indicated volcanic quiescence in its area of deposition. This is in marked contrast to the earlier Mesozoic units and to the Devonian and Pennsylvanian strata all of which contain abundant andesitic volcanic sediments and reflect arc type volcanic activity.

Rocks of the Nanaimo Group are essentially unmetamorphosed, although they show regional low grade alteration to the zeolite mineral laumontite (Stewart and Page, 1974). Their lack of metamorphism and the presence of prehnite clasts in Nanaimo conglomerates on Orcas Island suggest that the Nanaimo lies unconformably above and post-dates the deformed and metamorphosed rocks characterized by the minerals prehnite, pumpellyite and aragonite south of the Nanaimo (Vance, 1968). This metamorphism would thus be older than Upper Cretaceous.

There is evidence, however, that low grade metamorphism in the San Juan Islands involves more than one episode and may in part be post-Nanaimo. Pebbles in a conglomerate from the Lummi Formation of Orcas Island contain metamorphic prehnite and pumpellyite, while the Lummi itself is characterized by veins of metamorphic aragonite. This demonstrates at least two different periods of low grade metamorphism of similar facies in the San Juans. In addition it appears that pillow lavas on Lopez Island may be of Late Cretaceous or Tertiary age (Danner, 1966; Whetten, this bulletin). The metamorphism which produced pumpellyite and aragonite in these volcanic rocks would then be Tertiary and thus, younger than the Nanaimo. (Tertiary metamorphism in prehnite-pumpellyite facies, but without formation of aragonite, well known in the Olympic Mountains.) Tertiary metamorphism in the San Juan Islands would imply that the Nanaimo (like the Haro and Spieden Formations which are also unmetamorphosed) are juxtaposed against the metamorphosed rocks to the south along a fault of great horizontal displacement. Such a fault, however, is difficult to reconcile with the presence in the Nanaimo of Orcas and Waldron Islands of coarse conglomerates with a nearby southern source. Relations in the western Cascades indicate that prehnite-pumpellyite facies metamorphism which produced local aragonite is intra-Cretaceous. This metamorphism involves the Upper Jurassic-Lower Cretaceous Nooksack Formation and predates the overlying Chuckanut Formation of Early Tertiary age (Misch 1966; Vance 1968).

In summary, there is evidence for two and possibly three periods of prehnite-pumpellyite metamorphism in northwest Washington. Definitive age dating of key stratigraphic units and petrographic study of clasts in conglomerates will be needed to resolve this problem. Tertiary metamorphism is established for the Olympic Mountains and intra-Cretaceous metamorphism for the Cascades. Two episodes are represented in the San Juan Islands: either both pre-Nanaimo; or one pre-Nanaimo and the other Tertiary. Aragonite developed in the Cascade Mountains and in the second episode in the San Juan Islands. It is not known whether aragonite was formed during the first episode in the San Juans.

It may be noted that interbeds of contemporaneous volcanic rocks and volcanic sediments are lacking in the Nanaimo thus indicating volcanic quiescence in its area of deposition. This is in marked contrast to the earlier Mesozoic units and to the Devonian and Pennsylvanian strata all of which contain abundant andesitic volcanic sediments and reflect arc type volcanic activity.

The variety of sedimentary rocks in the Nanaimo reflects a wide range of depositional environments. Marine conditions are indicated by the presence of marine fossils in many parts of the stratigraphic section. Conglomerates containing thick-shelled fossil marine molluscs suggest deposition within or just below the tidal zone, while thin-bedded fossiliferous shales and siltstones reflect accumulation in quiet deeper water. The presence of cross-bedding in some of the Nanaimo sandstones points to vigorous currents and probable shallow water deposition. The coarse conglomerates of Orcas, Waldron and Stuart Islands are probably deltaic or floodplain deposits laid down by streams. Muller and Jeletzky (1970) have interpreted the Canadian Nanaimo in terms of four depositional cycles each of which begins with coarse, shallow water sediments and grades upward into fine grained deeper-water deposits.

In the San Juan Islands rocks of the Nanaimo Group and the concordantly overlying Chuckanut Formation have been deformed into a series of moderately tight upright folds with dips generally in the range 30 to 80°. Structural trends in the Nanaimo of the Canadian Gulf Islands and Vancouver Island are northwesterly. These trends change to WNW on Stuart Island to NE on Waldron Island and then swing back to WNW in the form of a large open S-shape, which conforms to major reentrants in the present outcrop pattern of pre-Nanaimo rocks on San Juan and Orcas Islands. These islands appear to have acted as a rigid buttress against which the Nanaimo and Chuckanut were folded in Cenozoic time. The broad NW-trending folds in the pre-Nanaimo rocks of Orcas and San Juan Island are discordant to and predate the Nanaimo folds.

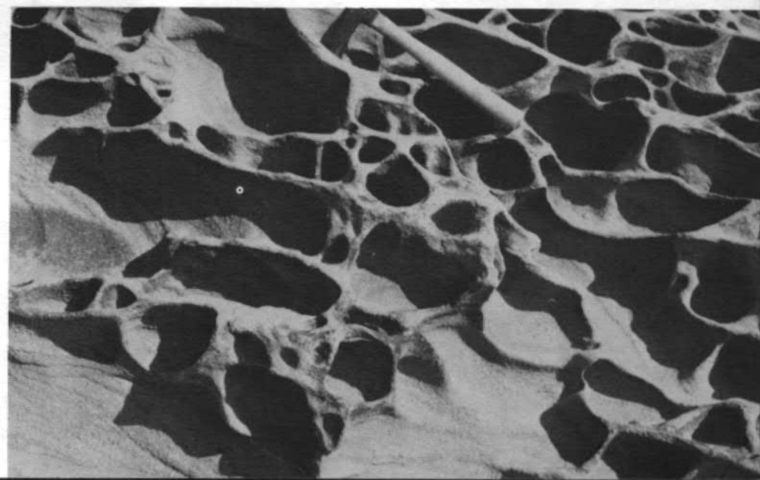
Chuckanut Formation(?)

The fossiliferous Upper Cretaceous rocks of southernmost Sucia Island are concordantly overlain by about 2500 feet of continental deposits, chiefly sandstone, which are here correlated with the Chuckanut Formation. Similar sandstones make up Patos, Matia, Clark and Barnes Islands. These sandstones are resistant rocks which form four members cropping out as strike ridges on the south flank of the Sucia syncline. Easily eroded rocks, probably siltstone or shale, are present in four covered intervals below and between the sandstone members. These weaker beds are covered by water or Quaternary deposits.

The exposed portion of this unit consists principally of medium to coarse grained buff sandstones. The sandstones are arkosic, contain abundant feldspar in addition to quartz and are typically cross-bedded. Honey-comb weathering is conspicuous in many beach exposures. Lenses and beds of pebble conglomerate are associated with the sandstones. Poorly preserved plant remains are common. The abundant quartz and feldspar in these rocks was derived from a granitic source, probably lying to the north. The predominance of cross-bedded sandstones in this unit suggests deposition by streams in a floodplain environment.

Breitsprecher (1962) and Ward (1973) correlated the Sucia sandstones with the De Courcey Formation of the Nanaimo Group. This correlation is strongly questioned

Fig. 11. Honeycomb weathering in cross-bedded sandstone of the Chuckanut(?) Formation, Sucia Island.



here as the De Courcey shows few features in common with the Sucia beds. In contrast to the Sucia rocks: it is relatively thin, generally 800 to 1,000 feet; it weathers grayish to greenish brown; it is generally finer grained; it lacks pervasive cross-bedding; and through much of its thickness it consists of sandstone beds 2-10 feet thick separated by shaly layers.

Fig. 12. Steeply dipping interbedded conglomerate and sandstone. Chuckanut(?) Formation, Sucia Island.

A more probable correlation of the Sucia sandstones is with either the Gabriola Formation, the youngest unit of the Nanaimo in the Gulf Islands, or with the Chuckanut Formation exposed on northern Lummi Island and in the Bellingham area. Both these units show strong similarities to the Sucia rocks. The Gabriola consists of up to 3,000 feet of yellowish sandstone, in part cross-bedded and with local lenses of conglomerate. Fossils have not been found in the Gabriola, but as it overlies well dated Nanaimo its age is either latest Cretaceous or Cenozoic. Correlation of the Gabriola with the Sucia beds is consistent with the fact that the Gabriola on Galiano, Mayne, and Tumbo Islands lies almost directly on strike with Patos, Sucia, Matia, Clark and Barnes Islands.

The Chuckanut Formation in its type area along Chuckanut Drive consists of approximately 11,000 feet of continental sedimentary rocks, chiefly sandstone, and shale. Study of fossil pollen from the Chuckanut (Griggs, 1966) indicates that the unit is largely of Early Eocene age, though the lower part of the section may be Paleocene. Similarity of rock types suggests the possibility that the Gabriola is equivalent to the lower part of the Chuckanut. Correlation of these units with each other and with the Sucia rocks is suggested here. This correlation should be tested by palynological study of the Gabriola and the Sucia beds and comparison of their pollen with that of the Chuckanut.

Fossils suggest that the Nanaimo conglomerates and siltstones of southern Sucia Island are equivalent to the Cedar District Formation of the Nanaimo of the Gulf Islands (Breitsprecher, 1962; Ward, 1973). The thick section of upper Nanaimo beds present between the Cedar District and Gabriola units in the Gulf Islands is absent in the Sucia section. This indicates the existence of a major disconformity in the Sucia section. On Lummi Island and in the Bellingham area the Chuckanut Formation lies directly on pre-Nanaimo rocks.

REFERENCES

Breitsprecher, C., 1962, Correlation of foraminifera and megafossils from the Upper Cretaceous, Sucia Island, Washington [M.S. thesis]. University of Washington, Seattle, Washington, 82 p.

Brown, E.H., and Bradshaw, J.Y., 1974, A layered gabbro complex in the San Juan Islands, Washington. Geol. Soc. America, Abs. with Programs (Cordilleran Sec.), v. 6, no. 3, p. 148.

Danner, W.R., 1966, Limestone resources of western Washington. Wash. Dept. Conserv., Div. Mines and Geology, Bull. 52, 474 pp.

Griggs, P.H., 1966, Palynological interpretation of the type section, Chuckanut Formation, northwestern Washington, in Kosanke, R.M., and Cross, A.T., eds., Symposium on Palynology of the Late Cretaceous and Early Tertiary. Geol. Soc. America Spec. Paper 127, 1970, p. 169-212.

Mattinson, J.M., 1972, Ages of zircons from the northern Cascade Mountains, Washington. Geol. Soc. America Bull., v. 83, p. 3768-3783.

Mattinson, J.M. and Hopson, C.A., 1972, Paleozoic ophiolite complexes in Washington and northern California. Yearb. 71 Carnegie Inst. Wash. Rept. of Director of Geophysical Lab.

McLellan, R.D., 1927, The geology of the San Juan Islands, Univ. Wash. Publ. Geol., 2, 185 p.

Misch, P., 1966, Tectonic evolution of the Northern Cascades of Washington State–a west-Cordilleran case history. Canadian Inst. Mining and Metallurgy Spec. v. 8, p. 101-148.

Mulcahey, M.T., 1974, The geology of Fidalgo Island and Vicinity, Skagit County, Washington [M.S. thesis] University of Washington, Seattle, Washington, 49 p.

Muller, J.E., and Jeletzkey, J.A., 1970, Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia, Geol. Surv. Can. Paper 69-25, 77 p.

Phifer, D.W., 1955, The geology of Stuart Island, [Senior thesis]. University of Washington, Seattle, Washington, 32 p.

Shelley, J.R., 1971, Geology of the western San Juan Islands, Washington State [M.S. thesis]. University of Washington, Seattle, Wash., 64 p.

Stewart, R.J., and Page, R.J., 1974, Zeolite facies metamorphism of the Late Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia, Canadian Jour. Earth Sciences, v. 11, no. 2 p. 280-284.

Usher, J.L., 1952, Ammonite Faunas of the Upper Cretaceous rocks of Vancouver Island, British Columbia. Geol. Surv. Can. Bull. 21, 182 p.

Vance, J.A., 1968, Metamorphic aragonite in the prehnite-pumpellyite facies, northwest Washington. Amer. Jour. Sci., v. 266, p. 299-315.

————————, 1974, Mid-Paleozoic Stratigraphy and metamorphism in NW Washington, Geol. Soc. America, Abs. with Programs (Cordilleran Sec.) v. 6, no. 3, p. 148.

Ward, P.D., 1973, Stratigraphy of Upper Cretaceous rocks on Orcas, Waldron and Sucia Islands, [M.S. nonthesis research paper]. University of Washington. Seattle, Wash., 44 p.

Whetten, J.T., 1975, The geology of the southeastern San Juan Islands.

PART II

QUATERNARY GEOLOGY AND GROUND-WATER RESOURCES OF SAN JUAN COUNTY, WASHINGTON

By
Paul A. Eddy

ABSTRACT

San Juan County is an area of major use of ground water in the State of Washington. Although the amounts of ground water used are not great it represents a major factor in the development and stability of the Islands.

Wells in the county produce water from Pre-Quaternary rocks, Pleistocene and recent material. The wells range in depth from less than 6 feet to more than 460 feet, with yields which vary from less than 60 gallons per day to 26 gallons per minute. The wide variation in yields is the result of the low hydraulic conductivity of the consolidated rock versus the higher conductivity of the unconsolidated material.

Ground-water use on most of the islands will be limited by the quantity of water available. Low storage coefficients of the rock allow only limited amounts of water to be stored underground. When the amount of water being used exceeds the quantity nature is storing, we will see a decline in the water level on the islands or an intrusion of salt water into the present fresh water aquifers.

INTRODUCTION

Purpose and Scope

The San Juan Islands are growing in both population and commercial development and both are largely dependent on ground water for their water needs. The development of the ground-water resource is hampered by the limited amount of water which aquifers will yield to wells and the intrusion of sea water where wells are overdeveloped. This portion of the report will define the availability of ground water and the development of the resource so that guidelines for its management can be established.

The investigation consisted of the evaluation of the ground-water conditions using the following as the basis for analysis:

1. Interpretation of the water-bearing characteristics of the various rock units.
2. Review of well logs and records in the area.
3. Consulting with drillers and obtaining well data.
4. Extrapolation of relevant hydrologic information available on various islands.

Information pertaining to the various rock units was obtained by researching previous work and field reconnaissance by the author. The field work, which consisted of well canvassing and geologic mapping, was carried out during the summer and fall of 1974.

Previous Investigations

The Pleistocene deposits of the Puget Lowland was first studied by I. C. Russell and Bailey Willis in 1889. Willis recognized two glaciations, the Vashon and Admirality, which are separated by the Puyallup interglaciation. Bretz (1913), McClellan (1927), Newcomb (1952), and Sceva (1957) used the terms Vashon and Admirality in their discussions of the Puget Lowland in Washington. A recent study by Artim has correlated the Quaternary deposits of the Puget Lowland based upon stratigraphic work by Newcomb (1952), Crandell and others (1958), Easterbrook (1963), Liesch (1963), Molenaar (1965), Mullineaux (1965), Kimmel (1968), Easterbrook (1968), Luzier (1969), and Molenaar and Noble (1970) (Figure 1).

Acknowledgements

The cooperation and assistance of many well drillers, well owners, and tenants who supplied information and allowed access to their land is gratefully acknowledged. The writer also acknowledges the county planning personnel who maintained the recorders and aided in other matters pertaining to the gathering of field data. The suggestions by R. H. Russell, Peder Grimstad, and Roger LeClerc, and other members of the Department of Ecology are also greatly appreciated.

Well-Numbering System

In this report wells and locations are designated by symbols that indicate their location according to the rectangular system for subdivision of public lands (Figure 2). For example, in the symbol 35/3W-29D1, the portion preceding the hyphen indicates successively the township north and range west (Township 35 North, Range 3 West) of the Willamette baseline and meridian respectively. Since the entire State of Washington lies to the north of the Willamette baseline, the letter "N" indicating North will be omitted. The wells which lie east of the Willamette meridian will have the "E", but the letter "W" will be omitted for all wells located west of the meridian. The first number following hyphen indicates the section (Section 29) and the letter "D" indicates the 40-acre subdivision of the section. The last number (1) indicates that this is the first well recorded within this particular 40-acre tract.

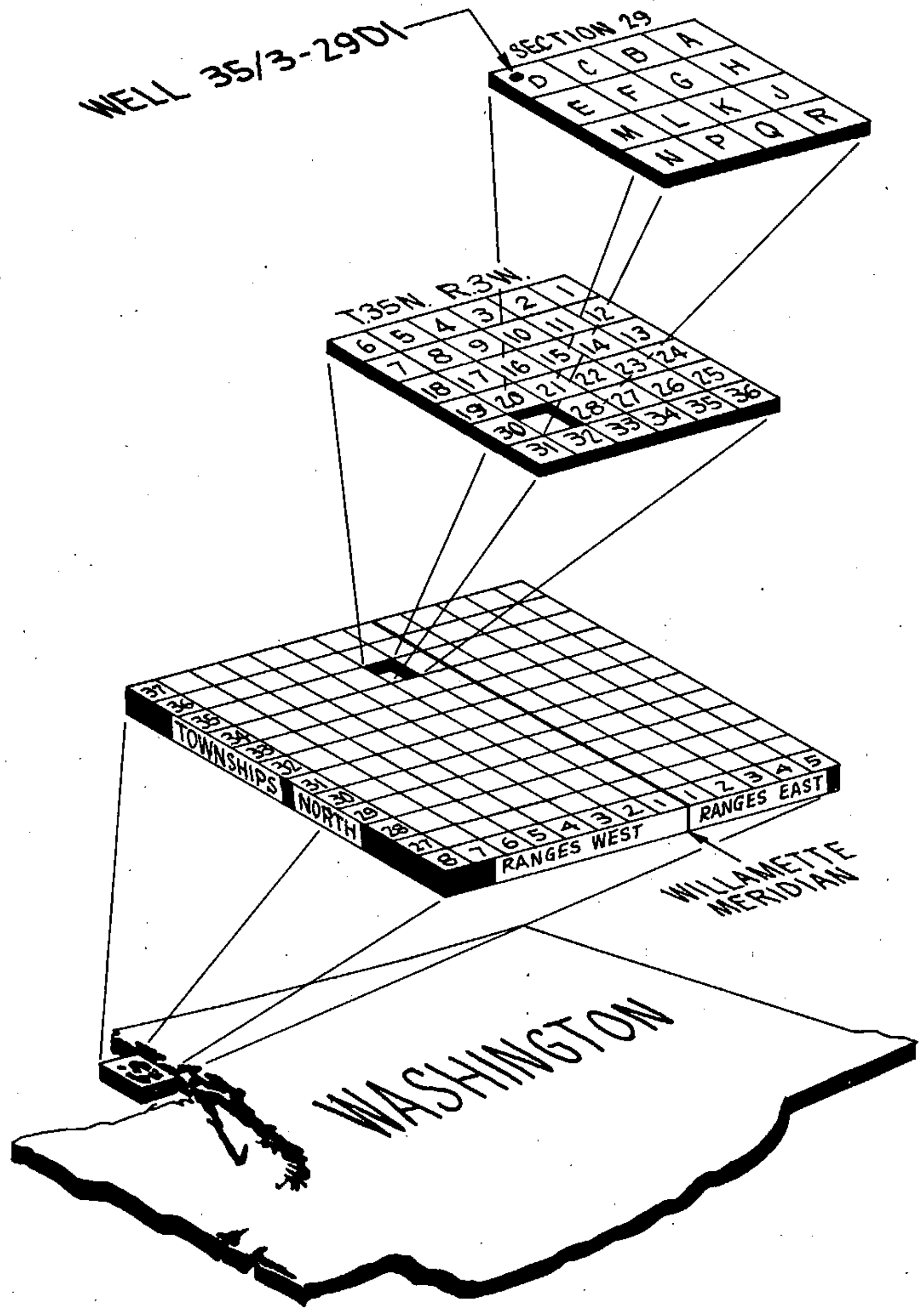


Figure 2. SKETCH SHOWING WELL-NUMBERING SYSTEM.

FIGURE 1.– CORRELATION CHART – QUATERNARY DEPOSITS OF THE PUGET LOWLAND

TIME UNITS	AGE (years)	GEOLOGIC CLIMATE UNITS	SOUTHERN PUGET LOWLAND: THURSTON COUNTY — Noble and Wallace (1966)[1]	MASON COUNTY — Molenaar and Noble (1970)	PIERCE COUNTY — Walters and Kimmel (1968)	SOUTHERN PUGET LOWLAND — Crandell and others (1958)	KITSAP PENINSULA — Molenaar (1965)	SOUTHWESTERN KING COUNTY — Luzier (1969)	KING COUNTY — Mullineaux and others (1965)	NORTHWESTERN KING COUNTY — Liesch and others (1963)	SNOHOMISH COUNTY — Newcomb (1952)	NORTHERN PUGET LOWLAND: NORTHERN PUGET LOWLAND — Easterbrook (1969)	ISLAND COUNTY — Easterbrook (1966)	WHATCOM COUNTY — Easterbrook (1963)	SAN JUAN COUNTY — Eddy (1974)	GEOLOGIC CLIMATE UNITS
RECENT		Recent Interglacial	Alluvium	Alluvium	Alluvium with mudflows	Alluvium with mudflows	Alluvium	Alluvium with mudflows		Alluvium	Alluvium ↓ older	Alluvium	Alluvium	Alluvium ↓ older Abbotsford outwash	Alluvium Non-marine Drift	Recent Interglacial
LATE PLEISTOCENE	10,000	Fraser Glaciation: Sumas Stade										Sumas Drift	Sumas Drift	Sumas Drift		Fraser Glaciation: Sumas Stade
		Fraser Glaciation: Everson Interstade	Lake Russell sediments	Lake sediments			Lake Russell sediments	Lake sediments				Everson Glaciomarine Drift	Everson Glaciomarine Drift	Bellingham Glaciomarine Drift Deming Sand Kulshan Glaciomarine Drift	Glaciomarine Drift	Fraser Glaciation: Everson Interstade
	12,500	Fraser Glaciation: Vashon Stade	Recessional outwash Moraine deposits Till Advance outwash Colvos Sand	Recessional outwash Moraine deposits Till Advance outwash	Steilacoom gravels Recessional outwash Till Advance gravel Colvos Sand	Recessional outwash Till Advance outwash	Gravels Recessional outwash Till Advance outwash Colvos Sand	Recessional outwash Ice contact deposits Till Advance outwash	Esperance Sand Member Lawton Clay Member	Delta gravels Recessional drift Till Advance drift Unnamed sand	Recessional outwash Marysville Sand Member Arlington Gravel Member Stillaguamish Sand Member Till Advance outwash Esperance Sand Member Pilchuck Clay Member	Till Advance outwash Esperance Sand	Gravels Till Esperance Sand	Till Mountain View Sand and Gravel	Recessional Outwash Till	Fraser Glaciation: Vashon Stade
	about 15,000	Olympia Interglaciation	Kitsap Formation	Skokomish Gravel Kitsap Formation	Kitsap Formation		Unnamed gravels Kitsap Formation		Nonglacial sediments	Upper clay unit	Admiralty Clay	Quadra Sediments	Quadra Formation	Cherry Point Clay		Olympia Interglaciation
		Salmon Springs Glaciation	Salmon Springs Drift?	Salmon Springs Drift	Salmon Springs Drift	Salmon Springs Drift	Salmon Springs Drift	Salmon Springs Drift		Unnamed gravels		Possession Drift	Possession Drift			Possession Glaciation
		Puyallup Interglaciation	Pre-Salmon Springs deposits Undifferentiated		Puyallup Formation	Puyallup Formation	Pre-Salmon Springs deposits Undifferentiated	Puyallup Formation		Lower clay unit		Whidbey Formation	Whidbey Formation			Whidbey
		Stuck Glaciation			Stuck Drift	Stuck Drift		Intermediate drift				Double Bluff Drift	Double Bluff Drift			Double Bluff Glaciation
		Alderton Interglaciation			Alderton Formation	Alderton Formation										
		Orting Glaciation			Orting Drift	Orting Drift		Orting Drift								
EARLY PLEISTOCENE?			Logan Hill Formation													

[1] See text for list of selected references.

After "Geology in Land Use Planning" by Artim, Information Circular No. 47, 1973

GENERAL GEOLOGIC SETTING, QUATERNARY

Pleistocene

The Islands of San Juan County lie along the northern edge of the Puget Lowland which is a topographic and structural depression between the Olympic Mountains and the Cascade Range. The larger islands in this archipelago are mantled with clastic deposits which are the direct or indirect product of glaciation and consist of till, drift, gravels, sands, clays and silts.

During the early to middle Pleistocene Epoch, climatic changes caused the continental ice sheet, which was located in Canada and Alaska, to grow and advance outward from British Columbia through the Strait of Georgia and override the San Juan Archipelago. As the ice moved across the area, extensive erosion removed earlier deposited unconsolidated material and scoured the underlying bedrock, leaving bosses of grooved, scratched, straited, and polished rock. Other materials were deposited as drift (moraines, eskers, etc.) by the ice as it moved through the area. Low areas were filled with outwash material from the advancing glaciers and were subsequently overridden by the ice. This material consists of a sand and gravel which is clay-rich. Climatic conditions again changed and a northward retreat of the ice mass resulted. As the ice retreated, large amounts of recessional outwash materials were deposited. With each successive change in the climate, the ice mass would again move into or out of the Puget Lowland.

There were three major advances and retreats of the ice mass, which have been named the Double Bluff Glaciation (the earliest), the Possession Glaciation, and the Fraser Glaciation (the latest). Because of the ability of an advancing ice mass to erode, little, if any, deposits of the Double Bluff or Possession Glaciations exists on the islands. A sequence of clay which overlies the bedrock in most places correlates closely with the till deposited during the Vashon stade of the Fraser Glaciation. This till is poorly sorted and consists of clasts which range in size from clay to gravel. Its induration is caused by the static pressure of overriding ice, and a clay and silt content in excess of 50%. The well logs prepared by the drillers labeled "hardpan" is believed to be this well indurated till.

In most places, there is a sequence of sands and gravels overlying the till. These sands and gravels, where present, correlate with the recessional outwash of the Vashon Stade and the Everson Interstade of the Fraser Glaciation. This recessional outwash is built by stream deposits or sheet wash deposits accumulating beyond the ice mass. The material is generally coarse grained sand, however, with extensive variations in the size of the grains both in the vertical and horizontal sections. Clay and silt are lacking because these finer and lighter particles are carried as suspended load farther downstream before deposition. As streams are the most common transport agent of recessional outwash, most outcrops display stratification in the form of foreset beds.

Where sea water came into or under the ice during glaciation, a glacio-marine drift was deposited. This drift varies in appearance from a packed sand and gravel to a clayey material with little gravel. The glacio-marine drift is limited to the north end of San Juan Island and parts of Shaw Island, and is identifiable in the field by the presence of marine fossils.

Large boulders were carried by glaciers or by icebergs floating in the area. These large rocks, called erratics, are so named because they are transported from the outcrops from which they originated and are not representative of the rock found in the area of their deposition. Erratics of large size can be found throughout the islands, and especially in and around Indian Cove on Shaw Island.

There was an uplift or rebound of the land surface, as the ice mass continued to retreat. As the land rose above sea level a nonmarine drift was deposited by the glacier. This drift consists of sand and gravel with some rocks to boulder size. As the ice mass continued to retreat, this drift became the last depositional unit resulting from glacial activity in the island area.

A review of the Pleistocene geology shows that the major portion of San Juan Island is covered with a thin veneer of glacial drift whereas, the northern end and southern tip have quite large thickensses of glacio-fluvial material. The gravel material exposed at Bald Hill on San Juan Island is moderately well sorted and stratified with foreset beds dipping southwesterly. McClellan described this location as a temporary terminal moraine; however, it now appears to be a recessional outwash deposited by meltwater streams. It is presently impossible to determine the stratigraphic relationship of the gravel to the till as no gradation or contact was observed in the field.

An area near the town of East Sound on Orcas Island has a thick sequence of glacially derived material. Orcas Island has extensive thin deposits of gravel and sand. Shaw Island has thick deposits of sand and gravel which are mixed with clay and silt of glacial origin. The only other island which appears to have an excellent cover of recessional outwash is Waldron Island. The remaining islands have only a sporadic thin veneer cover, if any, of glacially derived material.

Recent

As the ice mass retreated from the islands the land mass rose above sea level, and wave, wind, and stream action started reshaping the area. The glaciated surface of the islands have not been extensively modified by erosion during modern times except where unconsolidated sediments are exposed. As the ice receded from the area, sea water returned and wave-cut terraces, sea cliffs, spits, tomboles, bars, and other coastal features were sculptured and built from the easily eroded sediments. The newly developed bars, spits, tomboles, and hooks protected the unconsolidated sediments from continual wave erosion.

As pointed out by McClellan, there also appeared to be some elastic rebound of the islands after the retreat of the last glacier as shown by wave-cut benches which are presently above the high tide level.

As elastic rebound occurred, streams rejuvenated and started downcutting their channels and depositing the material in lakes along their watercourse, gradually filling them and causing the lakes to become marsh or swamp land. Where the streams emptied into the salt water, deltas were formed, often creating salt marshes. False Bay on San Juan Island is an excellent example of the transportation of sediments by stream action into a bay. It is now filled with sediment so that at low tide only a small portion of the bay contains water.

HYDROLOGY OF GEOLOGIC UNITS

Till

Till is a very poor aquifer because it lacks interconnected pore spaces. Further, it does not allow downward percolation of surface water which would recharge an aquifer. For the same reason, till will not accept water from septic tanks whose drain fields are constructed in this material.

Recessional Outwash

The void spaces in this material are open and interconnected which allows water to travel through the openings. For this reason, where the unit is present below the zone of saturation it generally contains enough water to supply domestic wells, and where there is enough thickness allows the installation of septic tank drain fields.

Glaciomarine Drift

The water-bearing characteristics of this material is poor since it contains basically the same constituents as till, with clay and silt serving as a cementing agent. Compactness is slight except where large thicknesses of the material exists. This unit has a low hydraulic conductivity and is unable to yield much water to wells.

Nonmarine Drift

Percolation tests for septic tank drain fields are good where this sand and gravel unit is above the water table. Water is obtained from shallow wells and infiltration trenches where the unit is saturated.

Spits and Tomboles

The spits and tomboles consisting of sand and other beach material have excellent porosity and where saturated, are sources for water. However, because of the proximity to sea water, excessive pumping leads to salt water contamination. The material where unsaturated is excellent for septic tank drain field, but pollution of the beach could result.

GROUND WATER

Hydrologic Setting

Contrary to common belief, ground water in San Juan County generally originates from local precipitation. All precipitation, however, does not go into the ground-water aquifer. A portion of it returns to the atmosphere by evapotranspiration (evaporation and transpiration through plants), a portion runs off as surface streams, and a portion is held in the zone above the water table by capillary action of the rock material. The remaining water infiltrates the soil and rock units to become part of the ground-water aquifer.

The amount of precipitation falling in an area varies with the season and the geography of the area as well as surrounding topography. Normally the evapotranspiration is highest during the summer months, and surface-water runoff is highest during the winter months. The areas that are steep and have very little ground cover either in the form of soil or vegetation tend to have higher amounts of surface runoff in comparison to areas with good ground cover and relatively flat topography.

In western Washington, including San Juan County, about 85 percent of the precipitation falls during a seven-month period from October through April (Figure 3). The period from May through September is water deficient when plants demand more water than falls as precipitation. This period of peak demand by plants is compounded by the fact that it is also the time when man puts maximum stress on the water supply.

In most areas in the islands, ground water is available at a reasonably shallow depth. Water levels in over 50 percent of the wells recorded are within 50 feet of the land surface as indicated in the following table which gives the average depth to water in a sample of 120 wells.

Water Level	*Percent*
Above land surface (flowing)	6
Below land surface	
0- 25 feet	27
26- 50 feet	18
51- 75 feet	13
76-100 feet	14
101-150 feet	14
151-174 feet	1
176-200 feet	3
over 200 feet	4
TOTAL	100

Recharge

Ground-water recharge is a function of the precipitation which occurs during the winter months between September and April. As stated earlier approximately 85 percent of the total precipitation falls during this period with the remaining 15 percent occurring during a time when evapotranspiration exceeds the precipitation and little or no water reaches the aquifers. The people of San Juan County would obviously experience a serious water deficiency if no ground-water storage existed to carry them through the dry seasons.

Figure 3 graphically shows the mean annual water budget in terms of precipitation income and evapotranspiration losses. The water budget for the islands is

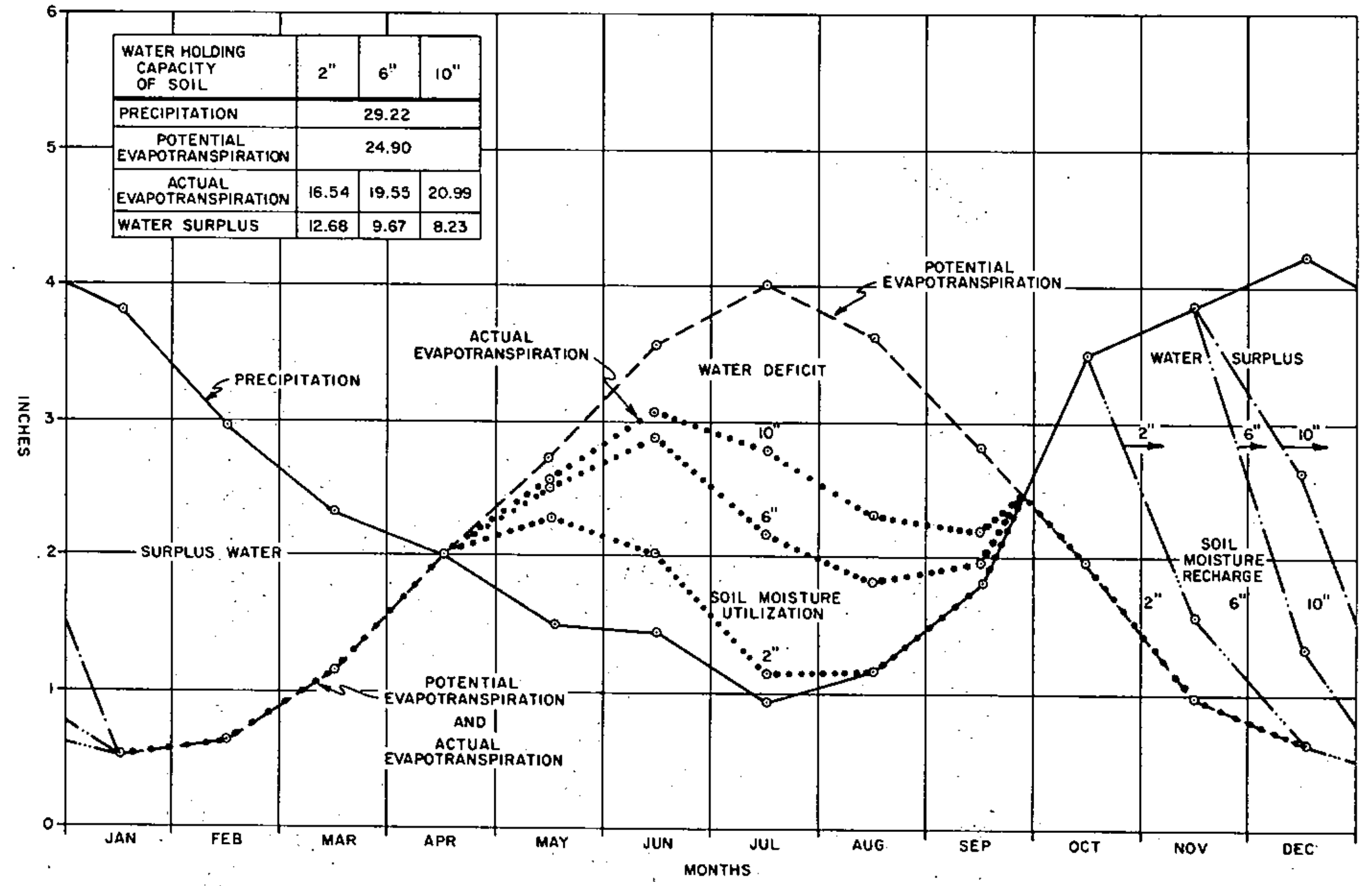


Figure 3. MEAN ANNUAL WATER BUDGET AT OLGA STATION.

plainly exhibited by curves on this graph. Starting near the midpoint of the graph it can be seen that as precipitation increases in the fall and evapotranspiration losses start diminishing, the precipitation curve crosses the evapotranspiration curve at a point represented on the graph near the end of September. As the soil moisture is replenished and becomes completely saturated, any additional precipitation will become available for surface water runoff or ground-water storage by deep percolation. When the storage capacity of the aquifers are reached, all other precipitation goes as surface-water runoff. When spring arrives the declining precipitation and increasing demands of evapotranspiration cause the curves to recross during mid-April at which time recharge to the ground-water aquifers stops.

The amount of precipitation which results in ground-water recharge varies greatly from place to place. Areas underlain by permeable material will receive more recharge than areas underlain by impermeable bedrock. This is evident by comparing the drainage patterns on Orcas Island with those of Lopez Island. Most of the precipitation which falls on Lopez Island is absorbed and is reflected by the lack of streams while Orcas Island has numerous streams indicating extensive runoff of surplus waters.

Discharge

Natural ground-water discharge is defined as the passage of ground water into surface water bodies such as streams, lakes or the sea. This discharge occurs when the water table is intercepted by a stream. Along the coastal areas much of the ground water discharges into the sea as springs which are usually below sea level.

Artificial ground-water discharge occurs by pumping water from wells or by allowing wells to flow. This type of discharge is only a small percentage of the total amount of water lost, but because of the limited capabilities of the rock to store water, it has a dramatic effect on the aquifers.

As expected, the direction of ground-water flow is toward areas of natural and artificial discharge. It moves from higher altitudes to lower altitudes, and where surface-water features are present, the ground water generally flows parallel to the drainage routes and in the same direction as the surface water flow.

Storage

In order for an aquifer to store water it must have voids of some type (fractures, joints, spaces between grains of rock, etc.). A ratio of the volume of voids to the total volume of rock is called porosity. The volume of water a

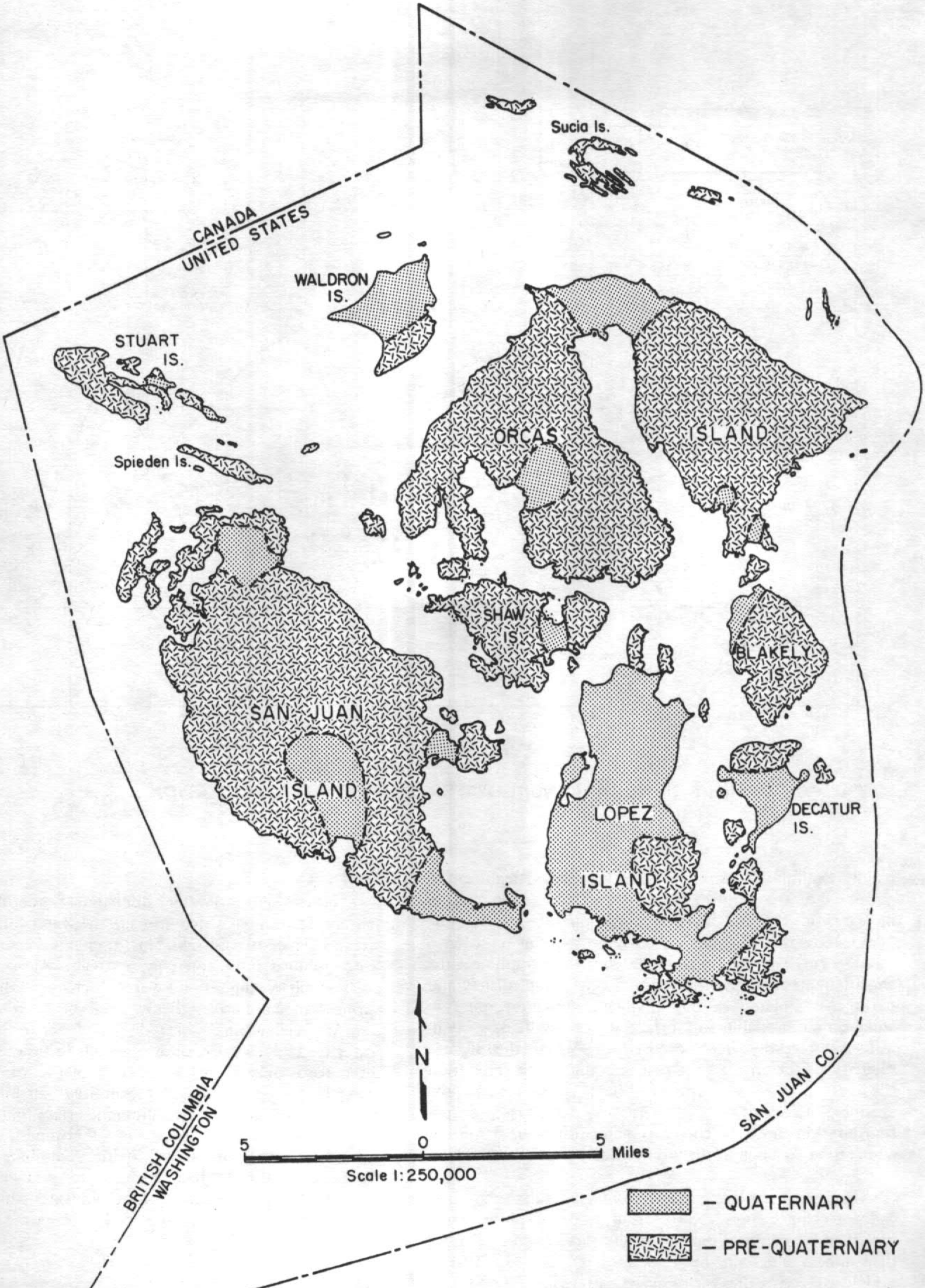


Figure 4. GENERALIZED AREAL DISTRIBUTION OF QUATERNARY AND PRE-QUATERNARY ROCK TYPES.

unit area of aquifer will release from storage per unit change in head is called the storage coefficient. The amount of water in storage is directly proportional to the porosity of the aquifer and that part of the water that will not be removed by drainage from the aquifer because of molecular attraction and capillarity forces holding the water against the forces of gravity. The amount of water not removed from storage is called the specific retention and the quantity which is drained by gravity is called specific yield. Both specific yield and specific retention are expressed as percent and specific retention plus specific yield equals effective porosity.

Storage changes are manifested by ground-water level fluctuations which are graphically portrayed by water-level hydrographs collected on the islands. These hydrographs will be published as separate items and will not be included in this publication. The hydrographs are for a well located approximately 1/2 mile north of False Bay (35/3-27N1) and a second well located about 1/3 mile from Garrison Bay near English Camp (36/4-25E1). The water level fluctuation shows distinct influence of tidal action. The short cycles being the results of tidal influence and the long-term fluctuations the result of the loss of water from storage by discharge (natural and/or artificial) or the gain of water by recharge.

Areal Distribution of Ground Water

Ground water occurs within two primary geologic units; the Quaternary unconsolidated material, and the bedrock or consolidated material of an older age. For purposes of ground-water evaluation wells in unconsolidated material are classified Quaternary wells and wells in the older consolidated material Pre-Quaternary wells. Figure 4 is a map showing the generalized distribution of Quaternary versus Pre-Quaternary material.

San Juan Island

San Juan Island is about 55 square miles in area. Two units are considered; unconsolidated materials (Quaternary), and older consolidated rocks (Pre-Quaternary) occur on the remainder of the island. Table 1 shows generalized well information on selected wells on San Juan Island.

Quaternary Wells

Although the alluvial deposits are widespread on San Juan Island, they do not contribute appreciably to the island's ground-water supply. The alluvium is relatively thin varying from 20-30 feet in thickness with only minor portions of this material saturated with water. To date, a limited number of wells have been drilled into this unit and of these, only a few produce enough water to supply multiple residences. Well logs and pumping data for two alluvial wells near Limestone Point (36/3-17E1 and 17E2) have reported bailing tests of 25 gpm and 10 gpm respectively. Both wells are approximately 45 feet deep and penetrate a series of clay, sand, and gravel layers. The most productive well on the island (70 gpm) is developed in gravel and is located near Mount Finlayson (34/2-8E1). Except for the possibility of sea water intrusion, this portion of the island has the highest potential for ground-water development. However, the ability of the alluvial deposits to provide additional ground water is questionable because the areal extent of this aquifer is limited.

Pre-Quaternary Wells

By far the greatest number of productive water wells drilled on San Juan Island are found in the Pre-Quaternary bedrock. These wells make use of the rock's highly fractured character (secondary permeability) which allows for the storage and movement of water. The more intensely the rock is fractured, the greater the possibility of it containing water.

There are a number of drawbacks to drilling for water in fractured bedrock: The amount of water in the rock is dependent upon fracture intensity, size of fractures, and on availability of water to fill the fractured area. A well may tap an aquifer which contains water in the fracture opening but little recharge is available, so that after pumping the well will go dry. Also, depending upon the transmissivity of the fractured rock, i.e. its ability to transmit water, pumping rates may have to be varied such that the well yield is inadequate for specific uses. The average rate is approximately 7 gpm on San Juan Island.

It should be pointed out that except for some specific pump tests the system which drillers use to establish the yield of a well is to first bail the well dry. After a period of time the well is then bailed dry again and the amount of water in the well is divided by the time it took for it to enter thereby giving a maximum amount of water that the well will provide. This amount is generally in excess to the quantity which a well pump will produce since a pump must be submerged and should also be above the bottom of the well. Therefore most quantities reported in this text are in excess to the amount which most wells will produce.

Summers (1972) in a study which he conducted on the specific capacities of wells in crystalline rock indicated that wells which are drilled close together into the same rock material may have substantially different specific capacities. The above listed anomalies greatly hamper accurate planning for future water well development in this type of rock unit.

The largest producing well in the Pre-Quaternary rock is near the entrance to American Camp (34/3-2P2) which was pumped at an average rate of 26.5 gpm over a 24 hour period and had a drawdown of 51.8 feet. These data indicate a specific capacity of 0.5 gpm per foot of drawdown (Cline, 1970).

Orcas Island

Orcas Island has an areal extent of about 57 square miles and consists of three areas of interest; the mountainous east and west portions in which water is obtained from bedrock; the east and west portions (unconsolidated materials) and the area between East Sound and the President Channel (unconsolidated material). Table 2 generalizes well information on selected wells on Orcas Island.

TABLE 1

GENERALIZED WELL INFORMATION, SAN JUAN ISLAND

As Reported By Ed Martel
Friday Harbor, San Juan Island

Location	Name	Depth (ft)	Quantity	Remarks
T36N, R4W (36/4)				
-13G4	Crow	270	0.5 gpm	Black shale
-13G5	Benford	50	5 gpm	Hard basalt?
-13G6	Siegel	50	4 gpm	Hard red basalt?

-26Q1	Garrison Bay Devel. Company	325	1.5 gpm	Black shale
-26R1	Pitts	160	20 gpm	Black shale
-26R2	Morrice	170	3 gpm	Basalt?
-26R3	Unknown	100	10 gpm	8" well, community supply - driller unknown
--------				
-28G1	Seattle Yacht Club	270	Dry	Shale
-28H1	Seattle Yacht Club	430	100 gpd	Shale, black, shot w/1400 lbs. powder
--------				
-35B1	Smith	155	9 gpm	Weeper - hard gray basalt
-35F3	Kelly	90	90 gph	Basalt?, sulfur
-35G2	Cox	270	2.5 gpm	Hard basalt?
-35L1	Marble	120	4.5 gpm	Basalt?, sulfur
-35L2	Daly	205	3 gpm	Unknown
-35L3	Unknown	200	Unknown	Reported salty
T36N, R3W (36/3)				
-33R1	E. Boyce?	165	12 gpm	5" well, pump test 12 gpm, 60' DD

-34N1	Pierce	165	18 gpm	Basalt?

Location	Name	Depth (ft)	Quantity	Remarks
T35N, R4W (35/4)				
-2D1	A. Nelson	170	25 gpm	Hard basalt?
-2L1	Williamson	122	2.5 gpm	"Weeper", hard basalt?
-2M4	A. Nelson	460	Dry	Black shale
-2N2	Fenner	165	5 gpm	Basalt?
-2N3	Unknown	200	1.5 gpm	Mostly shale, sulfur
-2P2	Miner	400	20 gpd	Black shale - shot with 1400 lbs powder - no increase in quantity
-2Q1	Miner	180	5 gpm	Basalt; 100' E. of 2P2

-11C1	Simons	460	20 gph	(Brown)
-11C2	Hitch	275	2.5 gpm	Most water at 250'
-11C3	Simons	360	18-20 gph	
-11F1	Robinson	220	0.75 gpm	Niggerhead coal seam?
-11F2	Unknown	160	2.5 gpm	8" well, "weeper"

-14A1	Gerhard	430	20 gph	Black shale
-14C1	San Juan Properties	200	18 gpm?	Red rock, hard
-14G1	Gerhard	100	2 gpm	Interlayered clay and bedrock
-14R1	C. Smith	225	0.5 gpm	190' basalt then ash

-25C1	Reverman	150	14 gpm	Water at 102; could not bail (DD) below 102
T35N, R3W (35/3)				
-2E1	Baer	160	10 gpm	Green tint to water, green cuttings

-3B2	King	75	4.5 gpm	

-19N1	Unknown	205	5 gpm	
-19P1	Unknown	260	2.5 gpm	

Location	Name	Depth (ft)	Quantity	Remarks
-22K2	Unknown	400	Unknown	
-22Q1	Harris	90	16 gpm	
-22Q2	Taylor	110	17 gpm	Old well
-22R1	Unknown	165	11 gpm	

-23A1	Peterson	300	30-40 gpm	60' DD, driller unknown
-23G2	Larsen	200	12 gpm	(Livermoore)
-23L1	E. Martel	197	Unknown	Red rock
-23L2	Boyce	200	1 gpm	Red rock
-23M1	Corner Store Area	170	5 gpm	
-23N1	T. Lawson	165	11 gpm	
-23N2	Scribner	165	5 gpm	
-23N3	T. Lawson	210	10 gpm	
-23P1	Murphy	130	30 gpm	
-23P2	Unknown	80	10 gpm	40-50' DD

-26A3	Wold	280	12+ gpm	
-26A4	Wiley	145	7 gpm	
-26B1	Unknown	130	17 gpm	Broken rock at 100' - liner in
-26D1	Unknown	100	1 gpm	
-26D2	Unknown	150	2.5 gpm	
-26D3	Hurney	165	7.5 gpm	
-26D4	Unknown	130	5.0 gpm	
-26D5	Lloyd	150	30 gpm	
-26E1	Unknown	250	Unknown	Reported "good yield" (Brown)
-26E2	Woods	100	Unknown	(Brown)
-26F1	Unknown	80	Unknown	4 house supply
-26G1	Golf Course	300	Unknown	Good producer (Livermoore)
-26K2	Golf Course	300	Unknown	Some sulfur
-26M1	Unknown	60	6 gpm	
-26N1	J. Lawson	300	Unknown	5" hole, very old

-27A1	E. Martel	50	10 gpm	
-27E1	D. Martel	280	10 gpm	Water at 210'
-27F1	Jackson	165	10 gpm	
-27G1	Unknown	200	5 gpm	
-27H1	Dr. Roberts	130	30 gpm	
-27J2	Oaks	130	30 gpm	(Enlow)
-27N1	Unknown	100	Unknown	Old well, 1 hp can't pump it dry, some sulfur

----

Location	Name	Depth (ft)	Quantity	Remarks
-28M1	Unknown	130	35 gpm	

-29G1	Unknown	270	2.5 gpm	
-29J1	Unknown	145	90 gpm	
-29J2	Unknown	130	13 gpm	
-29J3	Unknown	270	70 gph	

-30L1	Thomas	90	1 gpm	
-30M2	Unknown	90	1.5 gpm	Flint? very hard rock
-30N1	Unknown	270	7 gpm	
-30N2	Unknown	300	90 gpd	
-30Q1	Unknown	165	30 gpm	
-30Q3	Hamilton	300	1.5 gpm	
-30R1	Hannah Heights	190	30 gpm	4 hr. bailer test, 65' of water left in hole
---------				
-31A1	Schuelke	135	Flows .5 gpm	Pumped @ 10 gpm for 24 hrs, recovered to flowing in 10 min
-31A2	McGinities	125	5 gpm	

-32F1	Unknown	150	9 gpm	
-32F2	Unknown	156	13 gpm	

-33H1	Kronnen	105	70 gpd	(Enlow)

-34H2	Condon	120	5.5 gpm	(Brown)
-34H3	Unknown	102	1.5 gpm	
-34J1	Condon	370	7.5 gpm	
-34P1	D. React	310	10 gpm	Pumped for 25 hrs @ 10 gpm, DD to 260', SWL 20'
-34R1	Unknown	265	13 gpm	Water all the way down, most at 250' in qtz. seam
---------				
-35P1	Geneste	500	100 gpd	

Location	Name	Depth (ft)	Quantity	Remarks
T35N, R2W (35/2)				
-18D1	Carter	130	30 gpm	Water obtained at bottom
-18D2	Winn	170	5 gpm	"Weeper" SWL 12'
-18D3	Nash	170	11 gpm	@112' 2 gpm, SWL 0' @160' 11 gpm, SWL 60'
-18D4	Sheasby	160	6.5 gpm	
-18D5	Unknown	160	5.5 gpm	"Weeper" - reddish rock (Chert)?
-18J1	Lange	207	3 gpm	"Weeper"
-18J2	Lange	300	Dry	Black shale
-18J3	Unknown	270	Dry	Black shale
-18K2	Jones	112	17 gpm	Water at 102'
-18R1	Unknown	300	Dry	Black shale

-19A1	Unknown	300	70 gpd	(Livermore)
-19B1	Buck	270	2 gpm	"Hard gray basalt" SWL 20'
-19G1	Stephan	400	Dry	Black shale
T 34N, R3W (34/3)				
-2C1	Unknown	275	90 gph	
-2E1	Desermeaux	300	19 gpm	Driller Unknown
-2L1	Parks Dept.	200	25 gpm	(Meyers)
-2P2	Eagle Cove Develop.	200	Unknown	Good producer, will interfer with 34/5-2L1

-3G1	D. React	300	12-14 gpm	(Livermoore)

-11C1	Orvold	165	6.5 gpm	
-11C2	Albrecht #1	71	2.0 gpm	
-11D1	Albrecht #2	110	14 gpm	
-11E1	Albrecht	85	10 gpm	

* ( ) denotes driller other than Martel.

Pre-Quaternary Wells

Wells drilled into the Pre-Quaternary bedrock outnumber all other type wells by about three to one. Water in this rock material is from fracture zones and jointing which are similar to those in the bedrock of San Juan Island. In addition to the previously listed limitations for the production of ground water, Orcas Island has another problem; the rock units on the eastern portion of the island flanking the Mount Constitution and the Turtleback Ridge area are extremely dense and impermeable despite extensive folding and deformation.

In areas where the bedrock material displays dipping surfaces or jointing patterns which trend in the direction of sea water, extreme care must be taken to avoid the encroachment into the aquifer of salt water. Under natural conditions, the ground-water gradient along a coast line is toward salt water, and fresh water moves at a slow rate toward the sea. The fresh water and salt water are generally in equilibrium and with no wells affecting a ground-water system, the only time the gradient of the fresh water might be landward is during high tides, and then only near shore. When a landward gradient occurs as the result of pumping wells, the sea water will move toward the wells through the fractures or jointing of the rock. Since dipping surfaces and jointing give a higher hydraulic conductivity, and gradient, a rapid lateral movement of sea water along these planes can be expected. It is therefore, vital that excessive drawdown of the water levels in wells near salt water should not occur, and that these water levels should be maintained above sea level in order to preclude sea water intrusion.

Wells which obtain water from the Pre-Quaternary rock unit produce, in most cases, enough water to supply domestic needs. Although the yields vary greatly, they average around 8 gallons per minute. Of 52 wells sampled on the island, 40 indicated yields from 60 gallons per day (37/2-10K1) to 25 gallons per minute (36/2-7F3 and -21A3). Of these 40 wells, seven produced from 1 to 2 gpm; eighteen produced 3 to 7 gpm; ten produced from 9 to 16 gpm and five produced 20 to 25 gpm. The remaining twelve wells range from less than 60 gallons per day to "dry."

The depth to water of producing wells in this rock material varies from 85 feet to 500 feet below land surface, with the average being about 270 feet.

Quaternary Wells

East Sound–President Channel Area

This area was first studied by R. L. Washburn in 1954 as part of the Federal-State cooperative program. As a result of this study, it was determined that there are two major aquifers in the Quaternary material. First, a shallow aquifer which is perched on a till material and yields water to shallow wells and infiltration trenches. The water from this shallow aquifer is sufficient throughout most of the year for domestic and stock uses, however, during the late summer and fall the levels of water in the wells drop significantly. The major problem with the shallow aquifer is its susceptibility to contamination from septic tanks and other near surface sources of pollution. The deep gravel aquifer (below the till) is tapped by deeper drilled wells (50-105 feet) and appears to contain water in adequate amounts to supply for municipal or similar needs.

A review of this area indicated that very few shallow wells are now in use. Extensive drilling has been done into the deeper sand and gravel aquifer, and aquifer tests indicate that yields of 10-15 gpm can be obtained without drawing the level of the water in the well below sea level. Water rights on record with the Department of Ecology contain data indicating that yields of 20 to 25 gpm can be safely obtained if adequate spacing of wells is maintained.

The depths of wells penetrating this deeper aquifer vary from 21 feet to 230 feet with an average depth of about 95 feet. This sequence of fine grained sand, fine to coarse gravel, till, silt, and clay is the most productive aquifer on Orcas Island and with careful development will continue to produce adequate water supplies for future use in this area.

Other Areas

Although the remainder of the island is extensively covered by gravels, their thickness is limited and appreciable ground water is generally not available. Quaternary deposits in the West Beach area contribute water generally to large-diameter dug wells. The depth of the wells varies from 6 to 16 feet and have yields of 4 to 30 gpm. Near West Sound several wells obtain water from the gravel which varies in thickness from 15 to 30 feet. The wells are generally dug and produce from 5 to 10 gpm. The only remaining portion of the island which have wells in Quaternary deposits is along the shoreline on the southeast tip of the island. These wells are all dug and vary in depth from 8 to 28 feet. One well, reportedly, produces 15 gpm. Because the remaining wells supply domestic water only, it can be assumed that they produce about 5 gpm.

Shaw Island

Shaw Island which is about 8 square miles in areal extent, is divided into two ground-water producing zones. The unconsolidated rock area which is about one mile wide and is located between Blind Bay on the north side of the island to Indian Cove on the south side. The remainder of the island consists primarily of consolidated rock except where local sand bars, tombolos and spits occur along the shoreline.

Pre-Quaternary Wells

Due to the large extent of the consolidated rock, there are far more wells drilled into this material than the unconsolidated material. Wells in this material obtain water from the fractured zones and jointing in the rock. As in the Eagle Point area of San Juan Island, there are a series of quartz veins, which reportedly produce water regardless of the depth at which they are encountered provided they are below the saturated zone.

Wells which have been drilled close to the shoreline generally produce water of good quality. However, when bedding planes, jointing or faults trend directly seaward, sea

TABLE 2

GENERALIZED WELL INFORMATION, ORCAS ISLAND

As Reported By George Brown
Robinson and Noble Inc.

Location	Name	Depth (feet)	Casing Dia.	Casing Depth	SWL	Quantity	Remarks
T36N, R1W (36/1)							
-15P3	Virginia Lands LTD	22			13'		Elevation 40' Dug well

-16Q2	Rust	366	6"	20'	4'	3 gpm	
-16Q3	Dana	366	6"	11'	6'	3 gpm	200 ft. DD after 3 hrs. pumping
-16Q4	Steinmiezer	246	6"	10'	10'	6 gpm	
-16Q5	Tratarini	8	42"	8'	5'		Elevation 15'. Dug well
-16P6	Muckey	326	6"	6'	4'	2-3 gpm	Slight flow

-18G1	Burns	266	6"	12'	4'	4-5 gpm	
-18K1	Henry	446	6"	45'	41'	1 gpm	Slight Flow
T36N, R2W (36/2)							
-1R1	Burnett	300	6"	30'?	40'		Elevation 50'

-4B1	Van De Putte	24	36"	24'	4'		Elevation 75'
-4P3	Van Fleet	16			6'	10 gpm	Elevation 25'
-4R1	Rouleau	326	6"	32'	29'	5+ gpm	DD to 106' stabilized

-7B1	Frontenac Corp.	206	6"	23'		15 gpm	
-7C2	Deer Harbor (DH) Corp. (Williams)	326	6"	23'	27'	15 gpm	
-7E2	DH Corp.	246	6"	10'	15'	12 gpm	
-7F2	Fredrickson	366	6"	20'	1'	5-6 gpm	Elevation 25'
-7F3	Cayou Valley	126	6"	10'	23'	25 gpm	23' DD after 2.6 hrs. pumping

Location	Name	Depth (feet)	Casing Dia.	Casing Depth	SWL	Quantity	Remarks
-7F4	Issacson	300				6-7 gpm	Sea water
-7K2	Bush	182				5-6 gpm	
-7L1	Moore	206	6"	56'	9'	6-7 gpm	120' DD after 3 hrs, LSD 20'
-7M2	Lane	286	6"	18'	34'	2-3 gpm	
-7Q1	DH Marina	317	6"	78'	72'	25 gpm	105' DD after 3 hrs. pumping
-7Q2	DH Marina					4-5 gpm	Pump set 109'
-7Q3	Pratt	112	6"	76'	56'	7 gpm	

-10B1	Scotts Equipment	366	6"	15'	--	--	Dry 3 wells
-10C1	Holmes	315					1 hp pump

-15E1	Sandilands	346	6"	17'	87'	0.5 gpm	

-16B1	Exton	366	6"	10'	12'	1 gpm	
-16G1	Unknown	300+				3-4 gpm	Black to gray rock

-17N1	Issacson	300					2 wells - sea water
-17N2	McLaughlin	266	6"	10'	37'		
-17N3	Ryan	326	6"	22'	40'	1 gpm	

-18B2	Fehd	166	6"	91'	65'	8-10 gpm	

-21A4	Bryant	126					
-21A5	Orcas Water Users	466	6"	27'	24'	5+ gpm	

-22C2	Russell	34	36'	34'	12'		

-23J1	Bangs (Gutherie Cove)	366			3'	5 gpm	

Location	Name	Depth (feet)	Casing Dia.	Casing Depth	SWL	Quantity	Remarks
T36N, R3W (36/3)							
-1A2	Westmont	20			7.5'	5-40 gph	96" hole
T37N, R1W (31/1)							
-7M1	McConnell	40	Cribbing to 20'		1.4'		Low yield

-19M1	Glen	346	6"	36'	36'		Slight flow

-30P1	Rosario Highlands	200+				4-6 gpm	Sulfur
T37N, R2W (37/2)							
-13H1	Wright	11	72"	11'	2.1'	62 gpm	6' DD cannot maintain this yield, computed T=2800 Meinzers
--------							
-21G1	Frickson	6	36"	2'	5'	4 gpm	

water intrusion can be expected if the water in the well is withdrawn to the extent that the pumping level drops below sea level. The wells in this unit are low producers as on the other islands, and yields in excess of 3-5 gallons per minute should not be expected.

Quaternary Wells

The lowland area between Blind Bay and Indian Cove is covered by glacial drift material which, at the bluffs of Indian Cove, has a thickness in excess of thirty feet. If the thickness is consistent across the island, this unit should be a zone of production which presently is not being extensively exploited. Wells should probably be large-diameter and dug provided the depth to the saturated zone is not excessive.

Wells drilled near the shoreline in this unit have had problems with sea water intrusion. According to drillers' reports, the chance of contamination by sea water is extremely high, much higher than in wells drilled in the consolidated rock material. Therefore, future ground-water development in the unconsolidated material should take place far enough inland to minimize the possibility of sea-water encroachment.

The quantity of water obtainable from this unit is probably comparable to wells constructed in the shallow aquifer near East Sound on Orcas Island.

There are several tombolos and spits along the shoreline which may be capable of producing water. If these are developed, extreme care must be taken not to draw the water level down to sea level or below because of the proximity of salt water and attendant possibility of aquifer contamination, through infiltration.

Waldron Island

Lying approximately two miles northwest of Orcas Island is Waldron Island which has a surface area of about 4.5 square miles. This island is also divided into two ground-water producing zones. The unconsolidated rock which covers most of the island and the consolidated material which is exposed on the southeastern portion of the island.

Pre-Quaternary Wells

Well records are not available, but seeps were found along the southern shoreline indicating that if wells were drilled into this rock material small amounts of water could be obtained. The seeps were very small, about 0.002 cfs (1 gpm) which indicates that wells in this material would be very low in yield and would be limited to domestic needs.

Quaternary Wells

The unconsolidated material appears to have good water-producing characteristics. Along the north-eastern part of the island there is a sequence of sand that is greater than 40 feet thick. Where saturated, this unit should produce adequate quantities for domestic supplies. Lithology of the northern portion of the island varies from sand to clay and overlies consolidated material. However, several wells which appeared to be of low yield are located along this shoreline. The North Bay area is a low bank zone and wells appear to supply adequate water for summer homes. The Cowlitz Bay area has exposures of poorly sorted sand and gravel with a clay or silt binder. Several windmills are in operation in this region and it is assumed water is obtained from this sequence in which seeps were visible along a wave-cut bank. The total thickness of this sequence is not known, but it is assumed to be at least as thick inland as it is along the Cowlitz Bay area. The unit, possibly a good water producer, should yield water in amounts comparable to yields from wells in the unconsolidated material along the north shore of San Juan Island and in the East Sound area (10 to 15 gpm).

Stuart Island

Stuart Island is the most westerly island in San Juan County and is 2.8 square miles in surface area. It is divided into two ground-water producing zones: unconsolidated rock which is very limited, and consolidated rock.

Pre-Quaternary Wells

There are no wells in this material, but there are several seeps along the south flank of the island which is indicative that if wells were drilled that some water might be produced. Reportedly a spring exists on the south side of Tiptop Hill which has an unknown but "substantial" flow.

Quaternary Wells

Wells in this unit supply water to the residences on Stuart Island. It can generally be said that a well which is dug to a depth which reaches a blue clay will produce about 5 gpm. Wells drilled into the blue clay have proven unsuccessful. The water bearing zone appears to be a sand and gravel which ranges in thickness from 6 to 8 feet. The areal extent of this water bearing material is quite limited, as shown on the geologic map. (Fig. 4).

Sucia Island

This island lies directly north of Orcas Island and has a surface area of about 1.1 square miles. There are two aquifers on the island, one of which is known to produce water: The unconsolidated material in the narrow gaps between islands and the consolidated material.

Pre-Quaternary Wells

No wells of record have been drilled on this island, but seeps along the banks indicate that there may be small amounts of water from a series of fractures in the rock.

Quaternary Wells

Attempts have been made to obtain water from a blue clay material between the islands but salt water was encountered. There is however, a shallow sand and gravel with clay which yields sufficient amounts of water to supply the Washington State Park. The areal extent of this material is limited and does not show on the generalized geologic map. (Fig. 4).

Spieden Island

This island which has a surface area of about 0.75 square miles lies just north of San Juan Island. The unconsolidated material is of insufficient thickness to serve as a ground-water aquifer and, therefore, only the consolidated material is considered.

Pre-Quaternary Wells

No wells of record have been drilled on this island, but there are extensive seeps on the southern side of the island which indicate that water is contained within the rock. Although seeps were numerous they were small in volume. These seep areas should be examined in the fall of the year to determine if they continue to flow during low recharge periods. If they do, wells drilled along the southern slope of the island would have a very good possibility of producing water from a series of fractures each of which might contribute small amounts of water.

Johns Island

This island lies directly east of Stuart Island and has a surface area of about 0.35 square miles. There are two aquifers which could yield water to wells: The unconsolidated material on the southeasterly portion of the island and the consolidated material.

Pre-Quaternary Wells

Two wells in this rock unit supply water in excess of 5 gpm from a "sandstone." One well is over 200 feet deep and the other is 105 feet deep. They are reportedly used for community water supplies.

Quaternary Wells

The eastern half of this island appears to have from 10 to 40 feet of silt, clay, and some sand and gravel on top of consolidated material. As the island is traversed eastward, there is a gradual change in the unconsolidated sediments from a silty clay to a good clean sand and gravel containing rocks to 3 inches in diameter. Between a small bay on the northeastern side of the island and the beach on the south, lies a section of sand and gravel which appears to be a good potential producer of ground water. Because of low relief in this area the interval of water saturation above sea level would be limited. If the contact between the sand and gravel and the underlying consolidated rock is above sea level there should be little concern for sea water intrusion problems. However, if this is not the case, sea water may be present below the fresh water as it is under the tombolos and spits described on Shaw Island. If this situation exists, extreme care must be taken when pumping a well that the drawdown does not lower the water level in the wells near or below sea level.

CONCLUSIONS AND RECOMMENDATIONS

The Pre-Quaternary rocks yield small quantities of water to wells due to the low hydraulic conductivity of the material and areas of recharge, but most rock wells will produce 3-10 gpm of good quality water. As a result of the low yields obtained from this type well, it is recommended that if large developments are anticipated a series of low yield wells which are spaced to reduce interference should be used. Attempts to obtain greater amounts of water by drilling extremely deep wells will not substantially increase the yield. Even though this rock does not yield large amounts of water to wells, it is the most important water producing material on the islands.

The Quaternary material, in places, yields large enough quantities of water to supply town and industrial needs.

Where till is present the low hydraulic conductivity prevents water from percolating into or through to possible underlying aquifers. Dug wells which bottom in this material provide small amounts of water which is used for domestic and stock water needs. These wells are generally large diameter, low yielding, and many go dry or get very low water levels during the summer.

The outwash deposits, where saturated, are generally good aquifers. Where they are not saturated, septic tank installation would be acceptable, Wells in this material yield from 5-15 gpm. Beach deposits are very good as water producers, however, due to the proximity to salt water, sea water intrusion is a potential hazard.

Sea water intrusion probably will continue to be a problem where shoreline wells are present. The increased use of ground water at near-shore sites demands that some form of control over this resource be required. In order to prevent excessive movement of sea water toward wells the pumping should be restricted so that the pumping level does not fall to or below sea level. If this policy is followed, sea water should not migrate to the wells. If sea water intrusion occurs, replacement wells should be widely spaced and located as far from the shoreline as is feasible to prevent or minimize reoccurrence.

REFERENCES

Bretz, J. H., 1913, Glaciation of the Puget Sound region: Wash. Geol. Surv. Bull. 8, p. 224.

Cline, D. R., 1970, Test drilling and test pumping for water supplies for San Juan Island National Historical Park: Unpublished, p. 13.

Crandell, D. R.; and others, 1958, Pleistocene sequence in southeastern part of the Puget Sound Lowland, Washington: American Journal of Science, v. 256, no. 6, p. 384-397.

Danner, W. R., 1962, Guidebook for geological field trips, San Juan Island, Washington: University of British Columbia, p. 13.

Easterbrook, D. J., 1963, Late Pleistocene glacial event and relative sea-level changes in the northern Puget Lowland, Washington: Geological Society of America Bulletin, v. 74, no. 12, p. 1465-1483. (Whatcom County)

Easterbrook, D. J., 1966, Glaciomarine environments and the Fraser glaciation in northwest Washington: Guidebook for First Annual Field Conference, September 24-25, Pacific Coast Section, Friends of the Pleistocene, 52 p.

Easterbrook, D. J., 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington: Geological Society of America Bulletin, v. 80, no. II, p. 2273-2286.

Flint, R. F., 1957, Glacial and Pleistocene Geology; John Wiley and Sons, Inc. p. 553.

Kashef, A. I., 1972, What do we know about salt water intrusion; America Water Resources Bull., Vol. 8, No. 2, p. 282-293.

Liesch, B. A.; and others, 1963, Geology and ground-water resources of northwestern King County, Washington: Washington Division of Water Resources Water Supply Bulletin 20, 241 p.

Luzier, J. E., 1969, Geology and ground-water resources of southwestern King County, Washington: Washington Department of Water Resources Water Supply Bulletin 28, 260 p.

McClellan, R. D., 1927, The Geology of the San Juan Islands: PhD dissertation, University of Washington, p. 185.

Molenaar, Dee, 1965, Geology and ground-water resources. In Water resources and geology of the Kitsap Peninsula and certain adjacent islands: Washington Division of Water Resources Water Supply Bulletin 18, p. 24-50. (Kitsap County and parts of Mason, Pierce and King Counties)

Molenaar, Dee; Noble, J. B., 1970, Geology and related ground-water occurrence, southeastern Mason County, Washington: Washington Department of Water Resources Water Supply Bulletin 29, 145 p.

Mullineaux, D. R.; and others, 1965, Stratigraphy and chronology of late interglacial and early Vashon glacial time in the Seattle area, Washington: U.S. Geological Survey Bulletin 1194-0, p. 1-10.

Newcomb, R. C., 1952, Ground-water resources of Snohomish County, Washington; U.S. Geological Survey Water Supply Paper 1135, 133 p.

Noble, J. B.; Wallace, E. F., 1966, Geology and groundwater resources of Thurston County, Washington, V. 2: Washington Division of Water Resources Water Supply Bulletin 10, 141 p.

Noble, J. B., 1972, Preliminary water resources study San Juan County, Washington: Robinson and Noble, Inc., p. 50.

Schlots, F. E., 1962, Soil survey of San Juan County, Wash.; U.S. Dept. of Agriculture Series 1957, No. 15, p. 73.

Summers, W. K., 1972 Specific Capacities of Wells in Crystalline Rock: Ground Water Vol. 10, No. 8, Nov.-Dec. 1972, p. 37-47.

Walters, K. L.; Kimmel, G. E., 1968, Ground-water occurrence and stratigraphy of unconsolidated deposits, central Pierce County, Washington: Washington Department of Water Resources Water Supply Bulletin 22, 428 p.

Washburn, R. C., 1954, Preliminary investigation of ground water in the East Sound area, San Juan County, Washington: Open File Report, U.S.G.S., p. 25.

PART III

The Geology of the Southeastern San Juan Islands

By

John T. Whetten

INTRODUCTION

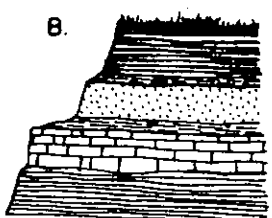
Describing the geology of the southeastern San Juans (Lopez, Decatur, Blakely, and adjacent islands) is a little like describing the texture and composition of a frosted fruitcake. Appropriately, the icing was laid down, in part, by a glacier in relatively recent geologic time. The cake was made long ago. Like all fine fruitcakes, this one, too, is improving with age. How to have the cake and eat it, too, is one of the central problems facing those who have an interest in preserving this spectacularly beautiful area.

The fruitcake analogy was chosen with some care. We often speak of "layer cake geology," and anyone who has had the pleasure of standing on a rim of the Grand Canyon knows why. The strata on the other side are continuous for miles, as far as the eye can see. As you descend into the Canyon it is easy to understand why the rocks get progressively older.

A.

Schematic representation of chaotic "fruit cake" geology.

B.

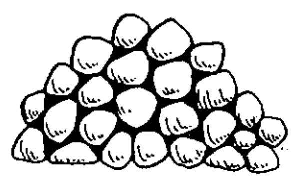


Conventional "layer cake" stratigraphic section.

This is not the case in the southeastern San Juans. Just as fruitcake is a random mixture of nuts, fruit, and chunks of other ingredients, so the bedrock is composed of blocks and pieces of rocks that are as different as nuts and figs. And just as the ingredients in the cake may have come from different places and be of different ages, the rocks in the bedrock, too, are of different ages and were originally formed in different places. Fruitcakes have a kind of "cement" made from flour and other ingredients. The bedrock, too, is well-cemented, but most of the cementing material is derived from ground up chunks of the primary rocks. With heat and pressure this mass (or mess, depending on your point of view) has consolidated. No rock type is a standard size. Some blocks are miles across, while others, composed of the same thing, are only a fraction of an inch.

The fruitcake analogy is intended to emphasize that the bedrock terrain is basically quite different from that which geologists are most familiar with in that (a) rock types are not continuous laterally and (b) as you go downward you don't necessarily get into older rocks. An additional characteristic is that rocks are intensely sheared. Although this type of terrain is by no means common, an increasing number of geologists on the west coast and in other areas are learning to recognize it. It is called *melange* (French, for mixture). In my view the bedrock of Lopez, Decatur, and Blakely Islands is a good example of a melange.

While a melange poses some exciting questions (Where did the blocks come from? When? How?), the surficial sediments have challenges of their own. Some of the sediments, particularly sands and gravels, have open pores filled with water. In fact, much of the available groundwater comes from this source. Sediments like clay and glacial till, on the other hand, have very little porosity and provide almost no water. How can you predict where and at what depth a sand or gravel layer will be reached when drilling a water well?

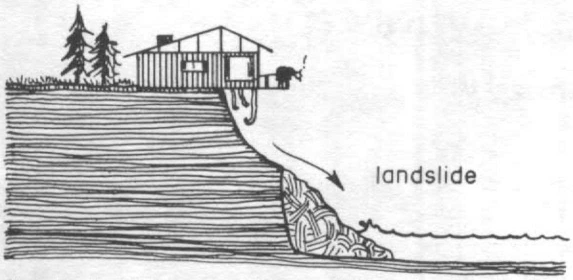


Dark areas between grains of sand are pore spaces in which water can collect and migrate.

The conditions that are unfavorable for the occurrence of water are also unfavorable for the disposal of liquid wastes, for it is no easier to get water into an impermeable bed than it is to get water out of one. The opposite is equally true. Effluent discharged from a septic tank drain field into a porous and permeable bed runs a good chance of contaminating nearby wells drilled into the same bed.

The best soils are usually developed on surficial sediments. The land is relatively flat and the sediments weather to soil faster than bedrock areas do. For maximum effective use of the land it makes good geologic sense to preserve these areas for agricultural purposes.

The surficial sediments commonly form steep cliffs a hundred feet or more high at the coastline. The cliffs are inherently unstable, and, in time, will slump and slide. A hazard is posed to unwary builders who, blinded by the superb view and flat land at the top, often perch homes near the edge. The hazard is intensified when the sediments become lubricated with septic tank effluent.



Sudden landslides can leave clifftop homeowners more view than they bargained on.

In the following pages we will be examining some geologic aspects of the bedrock and surficial sediments in order to understand a little better what's beneath our feet.

The information contained in this chapter was derived almost entirely from two and one half months of field work in the summer of 1974. It is a preliminary report, and would be much more complete if the publication deadline had allowed at least equal time for laboratory work, primarily in the microscopic and X-ray examination of rock and mineral specimens. The laboratory work is going on at the same time this is being written, and revisions will be made up to the printer's final deadline. The point to remember is that this is primarily a field description of the geology of the southeastern San Juan Islands. By no means is it the final word.

ACKNOWLEDGEMENTS

The many people who helped me in one way or another deserve warm thanks. Bob Russell of the Department of Ecology agreed to let me join his San Juan County water resource project and thus made this contribution possible. Funding came from the Department of Ecology through the State of Washington Water Research Center. Former San Juan County Commissioner Pat Roe and San Juan County Planning Director Bob McAbee provided advice, encouragement, and help from the county. Without exception, private landowners cooperated by giving me access to their property. Drillers Bud Thompson and Bill Freeman opened their drilling records and provided copies of well logs. Jan Muller (Geological Survey of Canada) and Ted Danner (University of British Columbia) helped me wrestle with stratigraphic problems, and Chuck Naeser (U.S. Geological Survey) provided fission track dates of the bedrock. Sue Cashman, Darrel Cowan, Bill Glassley, Stan Mallory, Bates McKee and Joe Vance, colleagues of mine at the University of Washington, were generous with advice and helpful comments. Peg Stroh drew the sketches. And finally, thanks to Paul Carroll, my field assistant, for his (usual) good humor, his patience, and his good geologic horse sense. As I recall, it was Paul who, after several days of trying to help me make sense of the badly shattered and sheared rocks at the southern end of Lopez, suggested that we might be working in a melange. That interpretation has led to an entirely new and different perspective on the geology of these islands.

SURFICIAL SEDIMENTS

The surficial sediments mantling the northern half of Lopez, the southern half of Decatur, and the western edge of Blakely are extensive and thick. Elsewhere the sediments are thin and discontinuous and bedrock commonly sticks up through them.

In one way or another, glaciers are responsible for much of the surficial sediment. Glaciers shaped the bedrock topography, provided sediment, and deposited glacial till. Like a succession of giant rasps, glaciers came out of the north from Canada and carved, scratched, and dug their way southward. Polished, scratched, and striated bedrock is commonly found, particularly along the coast. A small island in Outer Bay (Agate Beach), Lopez, has a very large glacial groove overlain by a small mound of glacially deposited sediments (Fig. 1). Grooves this deep are uncommon, but scratches and striations are not.

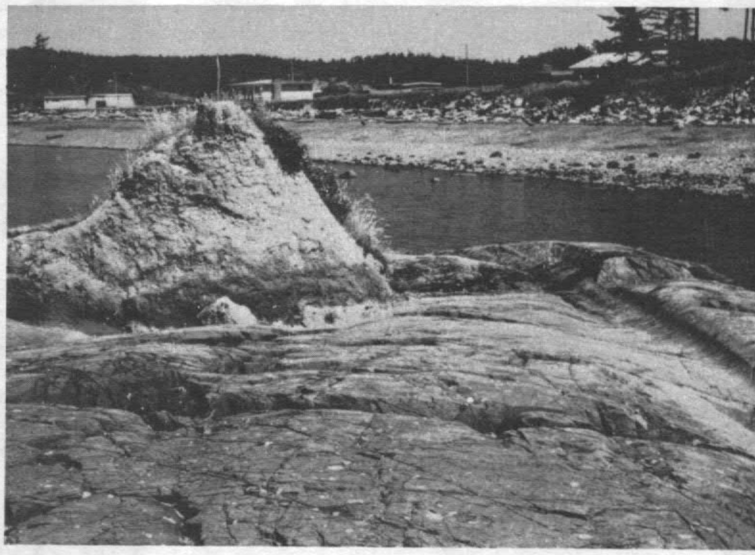


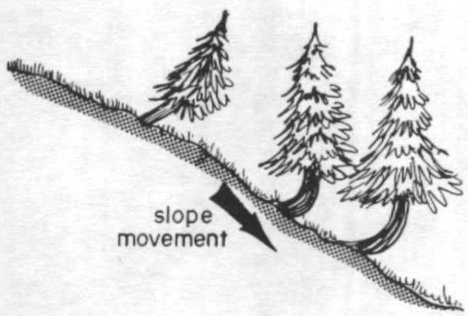
Figure 1. Glacial features on flysch-type sedimentary rocks on small island in Outer Bay, Lopez.– Smoothed and striated bedrock with glacial groove (right side) is overlain by a small patch of glacial till.

It is important to realize that at the time glaciers were active, sea level was 300-400 feet lower than at present. It takes a lot of water to make a glacier. The geography of the San Juans was indeed different in the very recent geologic past. The last glacier is thought to have receded from this area about 14,000 years ago.

Sediment-laden streams flowed from melting glaciers and deposited *outwash sediments*. *Advance outwash and interglacial sediments* were deposited prior to the arrival of the last glacier; *recessional outwash* was deposited as the glacier receded. In between is *glacial till* (the *hardpan* of well drillers), a dense, compact sediment deposited directly by a glacier, and *glaciomarine drift*, a till-like sediment containing fossils, which was deposited on top of the glacial till and attests to marine conditions at the close of glaciation.

Probably many glaciers advanced and retreated over the San Juans during the last two million years or so, but only the record of the last is generally exposed. Older glacial sediments may be preserved deep in the center of Lopez and Decatur, but we can't see them and we are not aware that they have been penetrated by the driller's bit. There is one exposure on the southeast side of Decatur where two tills appear to be present. The bottom one is under a thick section of advance outwash and interglacial sediment, which suggests that it is probably related to an older glaciation.

The surficial rocks are often well exposed as high, bold cliffs at the coastline. These cliffs were noted by early explorers who recorded "White Cliffs" on their maps of the southwest side of Lopez Island as early as 1858. The cliffs are *all* unstable. Small landslides and slumps occur frequently. Building should not take place near the edge even though the slope may look well-vegetated and stable. Notice that many trees growing on the steeper slopes are either leaning or have bent trunks because the soil beneath the trees has moved. In time, the leaning trees will bend to get back into a vertical growing position.



Leaning trees and trees with curved trunks are good indicators of active slope conditions.

Advance Outwash and Interglacial Sediments

Advance outwash is typically a medium to coarse grained, cross-bedded, well-sorted sand (Fig. 2). Gravel is present locally; it, too, may be cross-bedded (Fig. 3), or very poorly stratified in sub-horizontal beds (Fig. 4). Quantities of gravel are, unfortunately, quite limited; it is very useful for concrete aggregate and road ballast.

Cross-bedding is produced by migrating sand waves (or dunes) which occur when sandy or gravelly material is transported by wind, streams, or rivers. The advance outwash was deposited mainly by streams coming from an advancing glacier.

Advance outwash deposits are at least 50-60 feet thick on Lopez Island as determined by measurement of exposures on cliff faces. This is a minimum thickness,

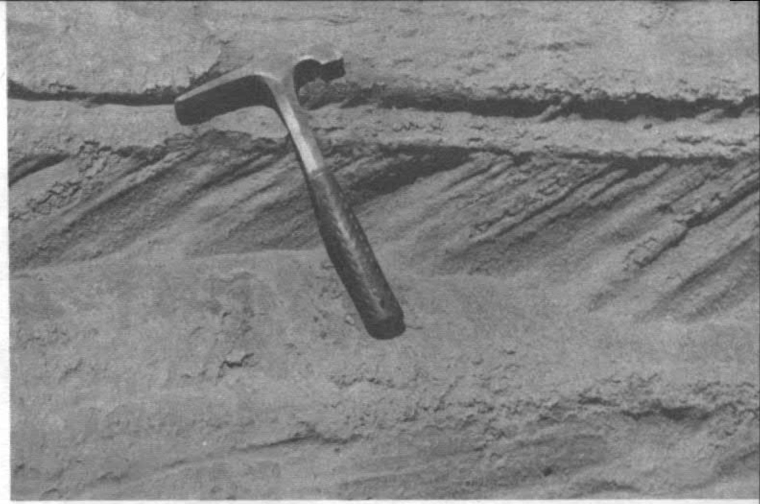
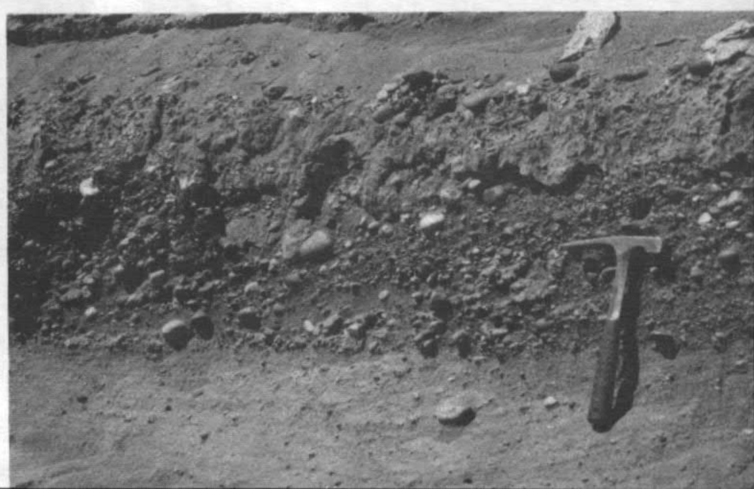


Figure 2. Cross-bedding in advance outwash sands, southeast side of Decatur Island.—The sand is well-sorted for size. Cross-bedding indicates deposition by a current, probably a river or a stream, which moved from right to left.

Figure 3. Cross-bedded gravels in advance outwash, Shoal Bay gravel pit, Lopez.—Cross-bedding indicates deposition by a current (probably a river or stream) which moved from right to left. A sand lens overlies gravels.

Figure 4. Poorly stratified advance outwash sands and gravels, south east side of Decatur Island.



however, because the base of the outwash is not usually seen. Approximately 95 feet of outwash sediments were measured on the southeast side of Decatur Island.

The effect of tampering with shoreline exposures of advance outwash sands is shown in Fig. 5, taken about a quarter mile east of Port Stanley, Lopez. Bulldozing stimulated the development of a gully and sediment fan, and the resulting erosion toppled trees and altered the shoreline. Unstable slopes are best left alone!

Figure 5. Environmental damage caused by human activity, Port Stanley, Lopez.–Bulldozing of advance outwash sands has caused gullying, slumping and deposition of a sediment fan.

Figure 6. Interglacial silts and clays, southeast side of Decatur Island.–These finely bedded silts and clays underlie advance outwash sands and gravels at this locality.

Interglacial sediments consist of finely bedded silts and clays with a few sandy layers (Fig. 6). Approximately 50 feet of silts and clays are exposed on the southeast side of Decatur Island, 70 feet are exposed on the west side of Blakely, and well-log data from Lopez suggests that the "blue clay" there may be hundreds of feet thick.

The advance outwash sediments overlie the interglacial sediments on Decatur Island, but on the west side of Blakely the interglacial sediments directly underlie the glacial till, and no outwash sediments are present. On Lopez, interglacial sediments are apparently very near the surface in the vicinity of Hummel Lake. Thus it is not known whether the interglacial sediments are entirely older, or partly older and partly contemporaneous with advance outwash sediments. We do know that before the glacier overrode the islands the outwash was extensively eroded, perhaps by meltwater streams from the nearby glacier, and perhaps by the glacier itself. This is indicated by the contact between outwash and glacial till, which is very uneven.

Glacial Till

Glacial till is a hard, dense, compact sediment which has a wide range of particle sizes (from boulders to clay) and compositions, but almost no sorting. It was probably deposited beneath the glacier, which accounts for its compactness and lack of sorting. Along the coastline it forms vertical to overhanging cliffs. Till was deposited on

Figure 7. Vashon Till overlying advance outwash sands, north of King's Point, Lopez Island.–Vashon Till (upper part of picture) is massive and forms a vertical cliff; advance outwash sands (lower part of picture) are cross-bedded and form steep slopes. Dark spot in upper left is caused by water "bleeding" from a slightly permeable part of the till on the cliff face.

outwash (Fig. 7), on interglacial sediments, and directly on bedrock (Figs. 1 and 8).

The till which is present over much of Lopez and Decatur Islands is called Vashon Till. This till is also widespread over much of the Puget Sound lowland. A thickness of 53 feet of Vashon Till was measured north of Kings Point on the southwest side of Lopez, which is probably close to its maximum thickness in the southeastern San Juans.

Figure 8. Vashon Till overlying volcanic bedrock, southeast side of Decatur Island.—The bedrock has been smoothed and striated by a glacier. The till is a dense, compact rock with no stratification and a wide range of particle sizes.

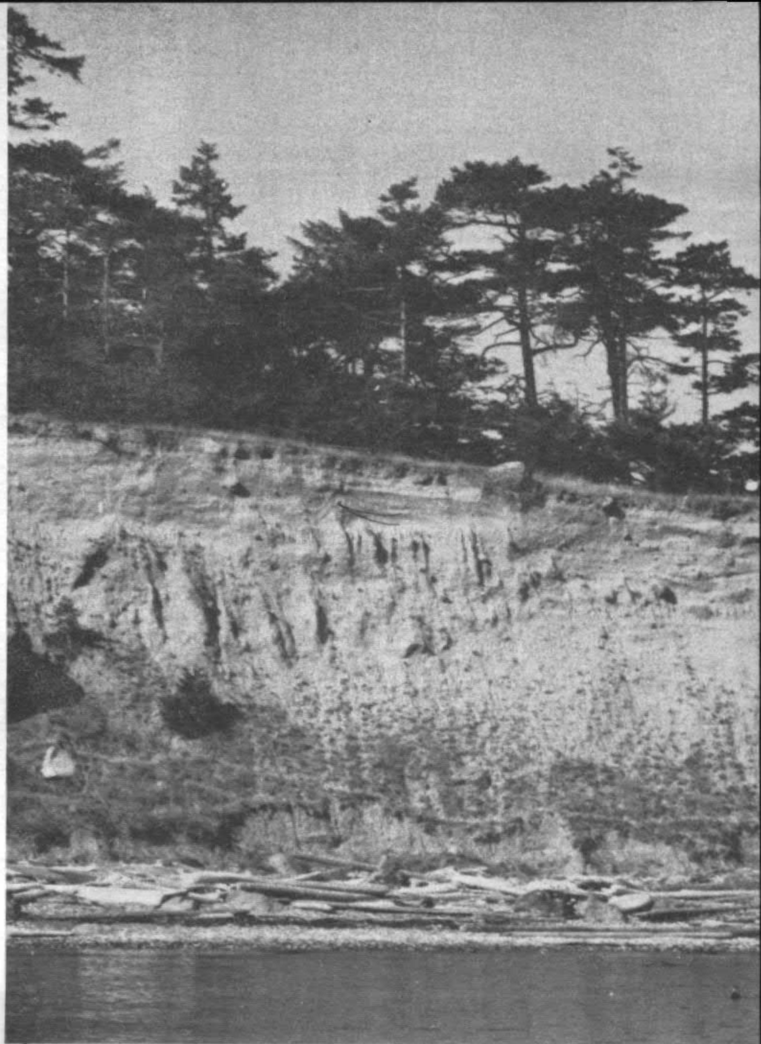


Figure 9. Vashon Till between Watmough Head and Point Colville, Lopez.—Notice the large erratic boulder (left side of photograph).

Some extraordinarily large boulders are present in Vashon Till (Fig. 9). Two erratics (called that because they didn't originate where they are now found) on the west side of Decatur Island are at least 50 feet in diameter. Erratics are found over most of the islands, and can be traced to northern sources. Their presence confirms that even the islands' highest summits were covered by glacier ice.

Vashon Till has all size ranges of material down to clay size. The clay helps give the till its compactness and, unfortunately, its impermeability. Well drillers aren't likely to find water in till, and many homeowners have had difficulty passing septic tank percolation tests when there isn't sufficient soil overlying the till at the spot where the drainfield is proposed.

Some outcrops of till appear to have poorly developed stratification. The stratified parts of till are normally quite thin in proportion to the overall thickness and may have been caused by a slight reworking of the sediment by water during glaciation. Often what appears to be stratification in till isn't stratification at all, but results from shearing of till by the moving glacier.

The base of the prominent cliff of surficial sediments on the southeast side of Decatur shows a spectacular example of ice thrusting of underlying sediments (Fig. 10). As the glacier overrode the area it plowed through the poorly consolidated interglacial sediments causing them to become tilted; some are even overturned (Fig. 11).

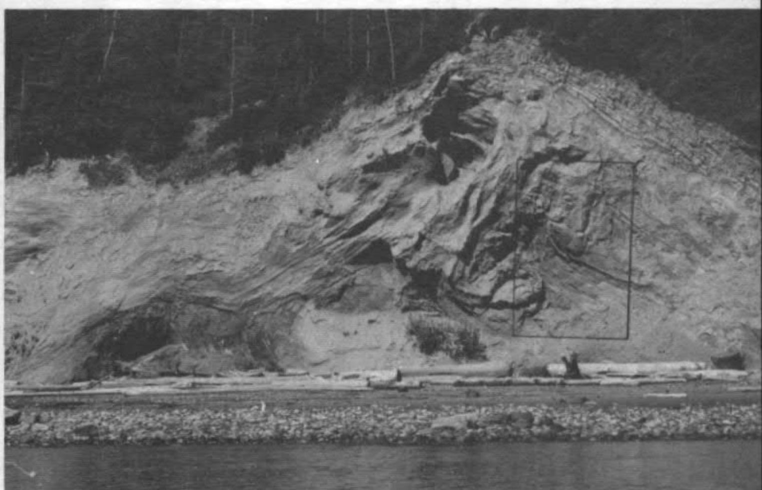


Figure 10. Ice thrusting of interglacial sediments, southeast side of Decatur Island.—The glacier which deposited Vashon Till caused tilting of interglacial sediments beneath it. Rectangle enclosed by black lines is shown in Figure 11.

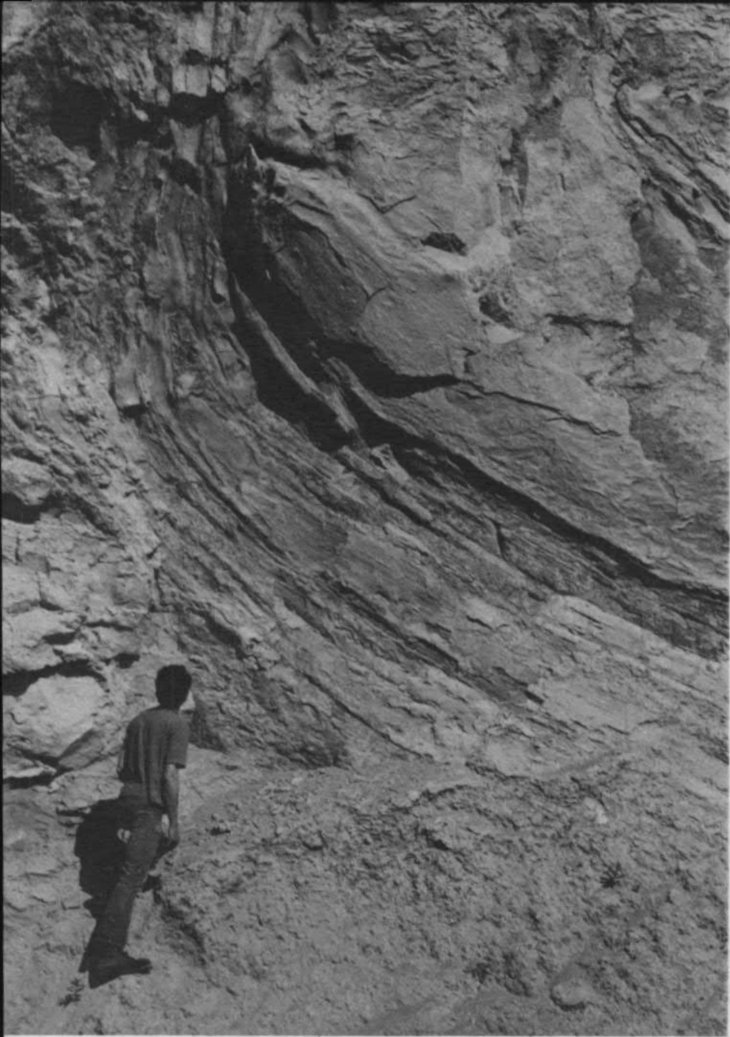
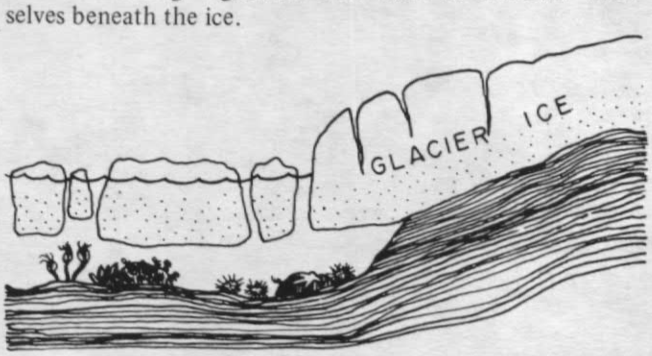


Figure 11. Detail of ice-thrust zone, southeast side of Decatur Island.—Interglacial sediments have been thrust by moving ice. In center of thrust zone, bedding becomes vertical (left side) and overturned (upper right). See Fig. 10.

Glaciomarine Drift

At the time the glacier which deposited Vashon Till was retreating, sea level apparently rose high enough to inundate some of the land and cause the glacier ice to float. It is not known whether the ice floated as one ice mass or as a large number of icebergs, but in any event marine bottom-dwelling organisms were able to establish themselves beneath the ice.



Establishment of benthic marine life beneath ice sheet.

The melting ice continued to deposit a till-like sediment in many places, but, because of the organisms that lived on the bottom, this sediment can be distinguished from normal till by the presence of articulated clams and other marine fossils. It is called glaciomarine drift (Fig. 12).

Glaciomarine drift usually appears nearly as dense and compact as till, but in some places it is considerably finer grained and shows poorly developed stratification.

Figure 12. Glaciomarine sediments, lagoon northeast of Davis Head, Lopez.—Small white spots near hammerhead are articulated clam shells in glaciomarine drift. Large clams in center of photo are in growth position in a beach deposit.

Mapping the distribution of glaciomarine drift is difficult unless you have a great deal of patience in looking for fossils. A thorough search would probably show that glaciomarine drift is widespread.

The thickness of glaciomarine drift is not well known, but is not believed to exceed 10 to 15 feet in most places.

Recessional Outwash

Recessional outwash is quite uncommon in the southeastern San Juans. It was noticed in two places. North of Kings Point on the southwest side of Lopez it consists of stratified sands and gravels with a few clayey silt beds with a total thickness of about 50 ft. Some parts of this deposit have nearly vertical beds (Fig. 13) which appear to have been deposited in cracks and fissures very close to melting ice. The abandoned gravel pit on the southeast side of Mackaye Harbor is probably the remains of an outwash delta. Here, beds of sandy gravel dip toward the south, suggesting that a body of fresh or marine water lay in that direction.

Figure 13. Ice contact sediment, north of King's Point, Lopez.– Poorly stratified near-vertical beds suggest deposition of sediment in a crack or fissure adjacent to melting ice.

Recent Sediments

Recent (post-glacial) sediments occur in stream valleys, on beaches, and on terraces adjacent to the sea. These sediments are usually sands and gravels, and sometimes they contain shell material from Indian middens.

The movement of sand along the coastline has created two unusually fine spits–Flat Point on the northwest side of Lopez (Fig. 14), and Spencer Spit on the northeast side (Fig. 15). In each case the source of sand is the eroding shoreline cliffs of advance outwash sand. The sand is transported by longshore currents to the site of deposition. Spencer Spit appears to be on the verge of connecting Frost Island with Lopez; other islands have been connected recently (for example, Humphrey Head and Fisherman Bay Peninsula).

Figure 14. Flat Point, northwest Lopez.–This spit was caused by the erosion of advance outwash sands on either side of the spit.

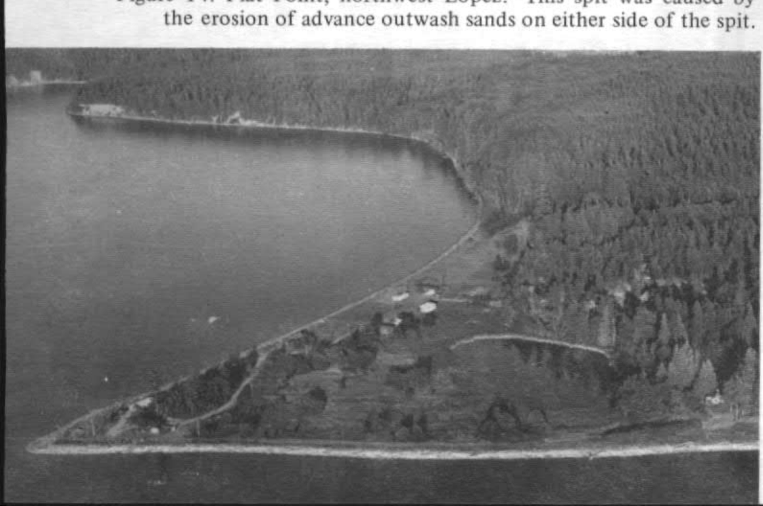


Figure 15. Hill in center of photo is underlain largely by advance outwash sands. This sediment is easily eroded, as illustrated by the human-caused erosion on the right side of the photo (Fig. 5). The eroded sediment is transported and deposited at Spencer Spit (left side). Frost Island is in the upper left corner.

Where to See Good Exposures of Surficial Sediments

1. "White Cliffs" along the beach north of Kings Point, southwest Lopez (Fig. 7). Here the sediments dip to the south, so as you walk north for about ¾ of a mile from the southern end of the exposure you walk through recessional outwash, Vashon Till, and advance outwash. The total thickness of sediments is about 200 feet.

2. Northward along the beach from the Lopez Post Office. This is an excellent exposure of Vashon Till which, near the top of the cliff, becomes less coarse and somewhat stratified and is possibly glaciomarine drift. The till dips to the south and advance outwash is exposed to the north along the beach.

3. Along the beach from Flat Point to Odlin Park, Lopez. The contact between the advance outwash sediments and the Vashon Till is exposed in many places. Because the contact undulates, you go from till to outwash and back to till as you walk along the beach.

4. County gravel pit on the Port Stanley Road, Lopez. An excellent exposure of cross-bedded sands and gravels (advance outwash) overlain by Vashon Till. The cross-bedding is particularly well developed at this locality (Fig. 3).

5. Beach exposure ¼ mile south of Spencer Spit, Lopez. Approximately 70 feet of advance outwash sand is exposed beneath till. The till-outwash contact dips southerly south of here, and as you walk south you encounter Vashon Till at beach level.

6. Small island on the south end of Outer Bay, Lopez. A glacial groove is overlain by a small patch of glacial till (Fig. 1).

7. Abandoned gravel pit at the northeast corner of Mackaye Harbor, Lopez. This is probably the remains of a delta of recessional outwash.

8. Lagoon northeast of Davis Head, Lopez. At the northeast end of the lagoon is an outstanding outcrop of glaciomarine drift with articulated clam shells overlain by a beach deposit containing fossil clams in growth position (Fig. 12). Please do not remove the fossils!

9. Along the west coast of Blakely Island from Bald Bluff north. Interglacial sediments (silts and clays) are overlain by Vashon Till.

10. Prominent cliffs on the southeast side of Decatur Island (Figs. 10 and 11). This is one of the most spectacular outcrops of surficial sediments in all of the San Juans. The Vashon Till is exposed at the top of the cliff (approximately 15 feet thick) beneath which is about 150 feet of bedded sediments, including advance outwash sediments (sands and gravels) and interglacial sediments (silty clays). An older till may underlie the interglacial sediments. An unusual feature of this exposure is the folding that has occurred in the bedded sediments; some beds are even overturned. It is likely that this deformation was caused by the glacier which deposited the Vashon Till, pushing on the weakly consolidated sediments below it.

Water-bearing Characteristics of Surficial Sediments

The surficial sediments on Lopez and Decatur Islands are probably the largest easily-tapped groundwater reservoir in San Juan County. There is relatively little water in glacial till or fine grained interglacial sediments, but the advance outwash sediments are normally coarse enough to have good porosity and permeability. Generally speaking, the coarser the sediment the better, as far as its potential as a source of groundwater.

Obtaining groundwater from surficial sediments involves drilling into porous sands and gravels that occur below the water table. It would be nice to have some sort of x-ray vision in order to look downward and see how deep you would have to drill in order to reach this sand and gravel. Although this talent (water-dowsing) is claimed by some, the majority find it more satisfactory to rely on geologic evidence.

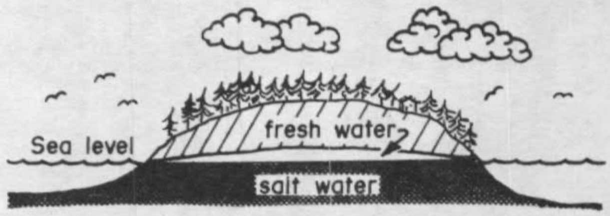
Geologic data come largely from well logs furnished by drillers. It is not easy to identify the ground up mess brought up at the end of a drill bit, and it takes some judgment to interpret the drillers' nomenclature. Nonetheless, Plate 2 is an attempt to draw geologic crosssections through Lopez showing bedrock, impermeable sediments, and sand and gravel. Most of the sand and gravel is probably advance outwash; it is not possible to say in every case whether the impermeable sediments are interglacial sediments or till.

Below the water table the sands and gravels should be water-bearing. Little water is likely to be obtained from impermeable sediments even below the water table.

The location of the cross sections is shown on the geologic map (Plate 1). A-A′ and B-B′ both trend southwest-northeast, while C-C′ trends northwest-southeast.

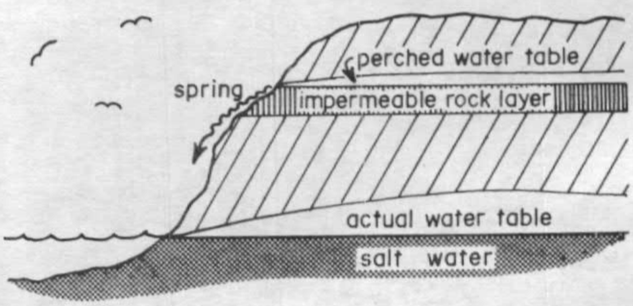
How deep should one be prepared to drill in surficial sediments? Perhaps the most instructive point of Plate 2 is that many wells drilled in sand and gravel terminate within a few tens of feet above or below sea level. Wells in impermeable sediments often end a hundred feet or more *below* sea level. This suggests that the regional water table is very near sea level, and when drilling in sands and gravels that is where you encounter water. When drilling in impermeable sediments (clays and till), however, it is often necessary to drill a considerable distance below the water table to get an adequate supply. Below-sea-level wells seem to be the general rule in the roughly triangular area bounded by the north side of Lopez Hill, Hummel Lake, and Spencer Spit (see the right side of cross-section B-B′ Plate 2), In summary, then, you should be prepared to drill to sea level unless you hit impermeable sediments, in which case you will probably have to drill deeper.

What about salt water intrusion? Fresh water occurs as a lens-shaped layer which floats on top of salt water because it is less dense. If you drill deep enough on the islands you will eventually hit salt water. The goal of the driller is to intersect the layer of fresh water–without drilling through it. The fresh water lens is thinnest at the coastline, therefore the greatest danger of salt water intrusion is in coastal wells that go below sea level.



Once fresh water is found, not much can happen to the supply unless water is withdrawn at a rapid rate for an extended period of time, which could lower the water table. If the water table is lowered too far too fast it is possible for salt water to intrude, either from below or from the side, and occupy the empty pore space. The easiest way of making sure that you never pump salt water is to see that your pump intake is never below sea level. If the water table is lowered sufficiently your pump may break suction, but at least it will never pump salt water. Once salt water intrudes into an aquifer it may take a long time (years), to remove it.

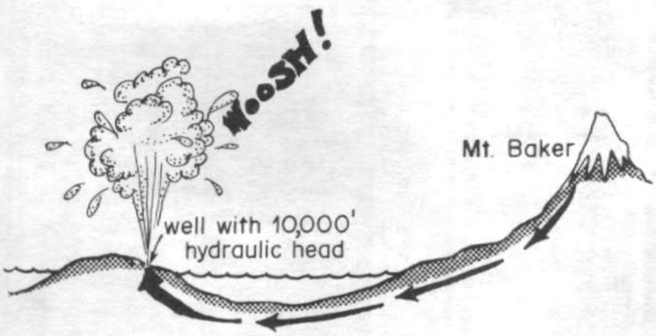
There are a number of small perched water tables within the surficial sediments. These generally occur on top of impermeable layers such as till or silty clay. Where till is exposed at or near the surface the ground is commonly swampy or marshy due to accumulated rainwater that moves downward very slowly through the till. Similar perched water tables exist beneath the land surface, and well drillers must be careful not to confuse a perched water table for the regional water body, or the supply of water could be very limited. Sometimes coastal cliffs of surficial sediments appear to be wet in certain zones (Fig. 7). This



"bleeding" usually occurs when a perched water table is intersected by the cliff.

Recharge to the groundwater body comes from rain water falling on the land surface which seeps downward through soil, sediment, and rock material until it reaches the zone of saturation. The top of this zone is the water table. It may take hundreds of years for water to reach the water table.

There are no underground streams, rivers, springs, lakes, or ponds. And, contrary to popular view, groundwater in the San Juans does *not* come from Mt. Baker. Assuming that there was some way of transporting Mt. Baker water, it is interesting to speculate on the consequence of discharging at sea level a pipe or tube filled with water with a ten thousand-foot hydraulic head!



There is, of course, a certain amount of risk in drilling water wells. A distraught person recently phoned to say that the driller was down 250 feet in "blue clay" in an area of surficial sediments that was supposed to have good water potential. What is the blue clay–Till? Clay beneath advance outwash? Water should have been encountered at about 100′ below land surface, but wasn't. What to do? Relocate and try again? Keep going in the same hole? Pull back the casing and try for water above the clay? These questions are difficult ones, and require the advice of an experienced groundwater geologist.

One bit of advice is offered: when developing a piece of property which will ultimately need water, you should make the well or water supply the *first* major investment, not the last. Too often the house is built first and the water system comes later. Should there then be a problem getting adequate water, the problem will be much worse if structures are already built.

BEDROCK GEOLOGY

It is surprising that more geologists haven't been attracted to working on the bedrock geology of the San Juans considering the great variety of rock types and structures that are present, not to mention the almost unbelievably pleasant and beautiful surroundings. Compared to many other regions our geologic knowledge of the bedrock is not very extensive–but geologic interest in the area is growing rapidly.

As explained earlier, the bedrock of the southeastern San Juans is a complicated jumble of blocks of rocks juxtaposed against one another by faulting and shearing. Some blocks are very large, perhaps up to a mile or more across, whereas others are almost microscopic. Some blocks show only minor internal folding and faulting, while others are intensely sheared throughout. Thus this melange, like almost all others, shows a baffling array of faults and shear zones, very few folds, and rock types that crop out in practically random order. In other types of more moderately deformed terrain, even though rocks may be broken by faults, it is possible to explain why different rock types occur where they do, and sometimes it is possible to predict which rock will occur over the hill or on the next island. Because these islands are so intensely deformed, this cannot be done.

Geologists feel obliged to classify and define. This seems to help explain things, even though we often oversimplify by doing so. The diverse types of bedrock occurring in the southeastern San Juan Islands have been grouped into five general categories: greenstones, flysch-type sedimentary rocks, volcanic rocks, plant-bearing sandstones and conglomerates, and serpentinite. Within categories there are some exceptions, most particularly among sedimentary rocks. Nevertheless, these rock types are the basis for mapping the bedrock in the southeastern San Juans (Plate 1): continuity and stratigraphic order have been severely modified. An added virtue of mapping rock types is the extra information it gives the planner and land user. In theory, at least, all rock types should be reasonably consistent in their properties. This is not necessarily true of formations.

Joe Vance has mapped the remainder of the archipelago in a more conventional manner. He takes the approach that rock types are stratigraphic, although he recognizes that they have been severely modified by faulting. Thus, he has mapped formations instead of lithologies. The difference in the two approaches is in part one of philosophy, but it may also be due to different conditions within the respective map areas. There simply has not been sufficient time to explore the two areas thoroughly and straighten out differences. One aspect is certain: the stage is now set for further examination and analysis of all the islands. There are still many questions to be resolved.

It would be an enormous help if we had more knowledge of the age of the rocks in the southeastern San Juans. Some dates were obtained from tiny zircon crystals by the fission track method, but fossils, the most common means of dating, are very scarce. Up to now the rocks have been most stubborn in their refusal to yield anything but squashed and smeared branches, stems, and twigs. Sooner or later some good identifiable marine mollusk fossils or microfossils will turn up to provide a basis for dating the rocks.

Some readers will be interested in knowing how the present mapping compares with that of Roy McClellan, who completed the first county-wide geologic map and report in 1927. McClellan's Leech River Group includes both the flysch-type sedimentary rocks and the plant-bearing sandstones and conglomerates. His Eagle Cliff Porphyrites are pillow lavas, and in some areas of Lopez Island, greenstones. He mapped Blakely and Frost Islands as part of the Turtleback Complex, which here is equivalent to greenstones. The positions of some of the contacts were changed in the current mapping, but on the whole McClellan did an excellent job. The main difference between our interpretations is in the structural interpretation of the bedrock based on information that wasn't available until more than four decades after McClellan completed his work.

Geologic Units

Greenstone

The greenstone unit consists primarily of coarse-grained igneous rocks that have been metamorphosed. Heat and pressure have changed some of the original minerals to a variety of green minerals, such as chlorite, epidote, and actinolite, that impart an overall green color to the rocks. This type of metamorphism is called greenschist facies. Because of weathering, you aren't likely to notice the color unless you crack open a rock and look at a fresh surface.

One of the main features of the greenstone unit is that it is composed of a number of different but possibly related rock types, no one of which can be traced very far, often not more than a few inches. Smooth surfaces, such as those that have been polished by ice and water, show a delicate intermixing of rock types in such a way as to resemble flow

Figure 16. Greenstone, west side of Mud Bay, Lopez.–Coarse, medium, and fine-grained igneous rocks are sheared together to form a highly deformed, recrystallized mosaic.

banding (Fig. 16). Bands frequently pinch and swell, change direction, intrude into higher or lower bands, and terminate altogether. It is not likely that this texture could be created by sedimentary or igneous processes, but is more likely due to tectonic mixing, underground, accompanied by shearing and folding. Rocks were broken and bent, and later annealed by heat and pressure.

If we look at a thin slice of rock with a microscope we can tell that the metamorphism preceded the shearing, because the metamorphic minerals are bent and deformed. We can also see that after the shearing the rocks were fractured, and prehnite and pumpellyite, minerals of relatively low metamorphic grade, developed in the fractures. It is not possible to say whether these metamorphic events are all separate, or whether they are related to one continuous metamorphism.

The rock types that most commonly occur in the greenstone unit are coarse- and medium-grained intrusive igneous rocks (gabbros, diabases, diorites, quartz diorites, and pyroxenites). Other rocks, including volcanic rocks and sedimentary rocks (sandstones and shales) are occasionally encountered, but they do not show evidence of greenschist facies metamorphism. It seems reasonable to postulate that they were faulted and sheared into the greenstone unit sometime after the main metamorphism. The greenstone unit includes some rock types that are similar to McClellan's Turtleback Complex on Orcas and other islands. It is uncertain whether the rocks are actually the same. The little information available about their ages suggests they may be different. The Turtleback is a very old rock (Mattinson (1972) dated it as early Paleozoic), but a fission track age on zircons from a greenstone sample from Jones Bay, Lopez, indicates that this rock didn't cool from metamorphism until Early Cretaceous.

Large areas on Lopez and Frost Islands and a small part of Decatur Island consist of greenstone. Some of the best exposures on Lopez are a few small outcrops on Jones Bay, where the texture is superbly displayed; on the north coast of Mackaye Harbor; and the high headlands on either side of McArdle Bay. Lopez Hill is composed of greenstone, and good exposures are found at its base along Lopez Sound.

Rocks on the southern end of Blakely Island are very similar to the greenstones on Lopez Island, but rocks on the northern two-thirds are different. Except for the northern tip of the island, which consists of flysch and volcanic rocks, coarse grained intrusive igneous rocks predominate. Many are layered, and shearing is much less evident than in the Lopez greenstones. Time did not allow more than a brief reconnaissance of Blakely Island, and it is not known how these rocks relate to the greenstones. Out of necessity they are all mapped as the same unit. Blakely Island is a critical area deserving of detailed mapping.

Flysch-type Sedimentary Rocks

Black, blue-gray, and sometimes lighter colored sandstones, shales, conglomerates, and cherts are exposed on the southwest coast of Lopez and on Center Island. Excellent exposures are found at Kings Point and Iceberg Point (Lopez), Charles Island, Long Island, all around the coast of Center Island, and many other places.

The main characteristic that these rocks have in common is stratification or bedding. Thin beds of sandstones commonly alternate with thin beds of shale (Fig. 17). Sometimes there is cross-bedding (resembling the cross-bedding found in the advance outwash deposits) (Fig. 18), but graded bedding (Fig. 19) is more common. Graded bedding results from deposition by a waning current; the

Figure 17. Flysch-type sedimentary rocks, Charles Island.–Folded thin beds of sandstone (lighter color) and shale (darker color). Some of the sandstone beds are braded, suggesting deposition by turbidity currents. Beds dip to the right and are upside down.

largest and heaviest particles drop first, followed by the lighter ones. Moving slurries of muddy water, called turbidity currents, probably deposited many of the graded beds. Sedimentary sequences characterized by turbidity current deposits are sometimes called *flysch*.

Figure 18. Cross-bedded conglomeratic sandstone, Deadman Island. –Relatively coarse clastic sequences with cross-bedding and channeling suggest submarine fan deposition.

Figure 19. Graded sandstone bed, James Island.–Upside down sandstone bed grades from coarse (upper right) to fine (lower left). Cross-beds (center) indicate waning flow conditions during deposition.

Chert fragments and volcanic fragments seem to be the most abundant constituents of both conglomerates and sandstones. The source of these particles is unknown.

The flysch-type sedimentary rocks were probably deposited in a deep water marine environment. Some sequences, as exemplified by the graded and sometimes cross-bedded conglomerates, sandstones, and shales on Deadman Island, may represent parts of ancient submarine fans.

Chert beds occur in the flysch-type sedimentary rocks and deserve special mention. Chert is an extremely fine grained rock composed primarily of silica derived from the accumulation and breakdown of the shells of microscopic organisms with siliceous hard parts. Chert is sometimes interbedded with shale, and thin beds of chert and shale can be seen on the south side of Outer Bay and along the small south-facing bay between Iceberg Point and Aleck Bay.

Another good chert exposure occurs on the east end of Johns Point (Fig. 20), in contact with volcanic rocks. This chert has been deformed into a very impressive set of closely spaced folds.

Figure 20. Bedded chert, Johns Point, Lopez.– Relatively thick beds of chert probably formed by the recrystallization of siliceous microorganisms on the sea floor. Beds are unevenly thick due to post-depositional deformation.

The age of the flysch unit is unknown. Zircons from volcanic cobbles in a conglomerate on the southwest side of Long Island give an Early Cretaceous age by the fission track method, but since the rocks are metamorphosed (prehnite-pumpellyite facies) this is probably a metamorphic age rather than a formation age. No fossils have yet been found in the unit despite countless hours of searching.

There are some "one of a kind" rocks that have been grouped with this unit for convenience. On Iceberg Point (Fig. 21) there is a shale-chip sandstone (Fig. 22), and breccias, limestones, and sandstones occur near Thatcher Bay on Blakely Island. More detailed mapping may demonstrate that these rocks belong to some other unit.

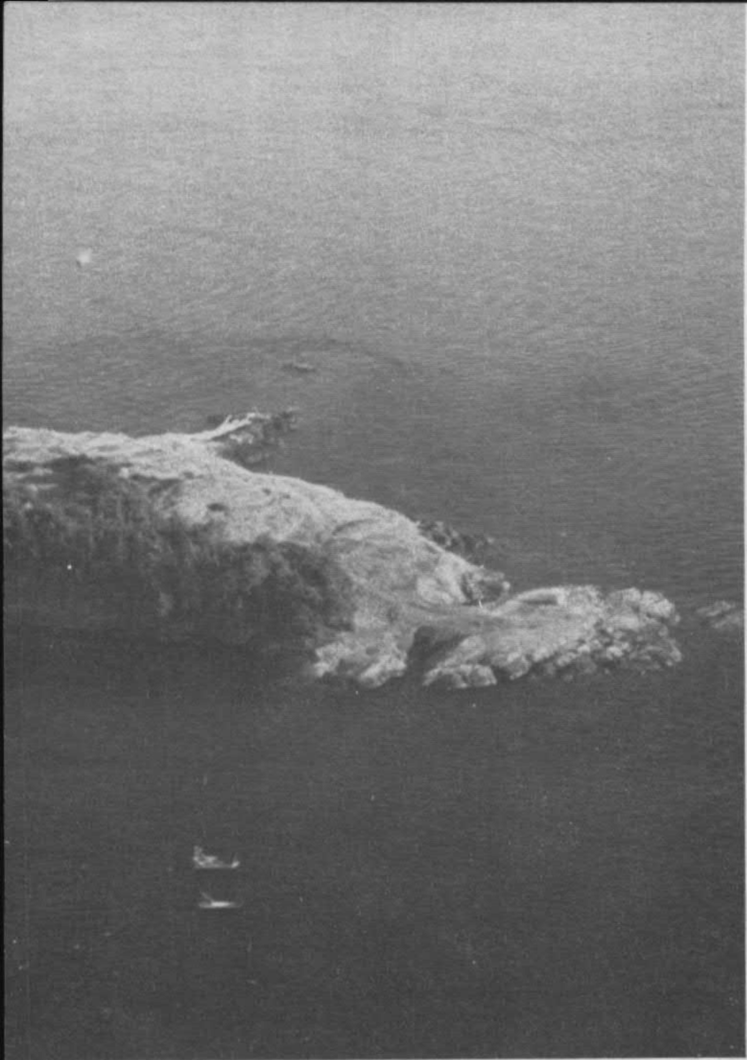


Figure 21. Iceberg Point, Lopez.–Shale chip (intraformational) sandstone occurs along far coast. More normal flysch-type sedimentary rocks occur in foreground. Iceberg Point is Federal property controlled by the Bureau of Land Management.

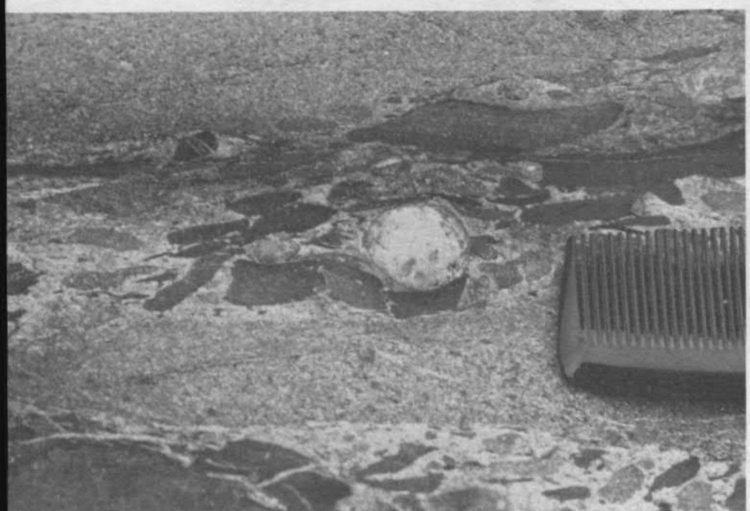


Figure 22. Intraformational conglomerate, Cattle Point, San Juan.–Shale chips indicate erosion of fine material within the depositional basin at the time that sand layers were deposited. Shale chip sandstones also occur on Iceberg Point, Lopez. Clast in center is of intrusive igneous origin.

Some of the flysch-type sedimentary rocks are highly deformed by shearing, while others are not. Shales are most easily sheared, and thick shale units appear to have deformed almost like toothpaste squeezed from a tube. Sandstones are more brittle than shales, and where the two are interbedded and sheared, the sandstone beds commonly break up into small chunks that appear to float in a fractured shale matrix (Figs. 23 and 24).

Figure 23. Intensely sheared flysch-type sedimentary rock, Cattle Point, San Juan.–Lighter colored splotches are sandstone clasts that once formed continuous beds. Sandstone is brittle whereas shale (darker color) tends to flow under stress.

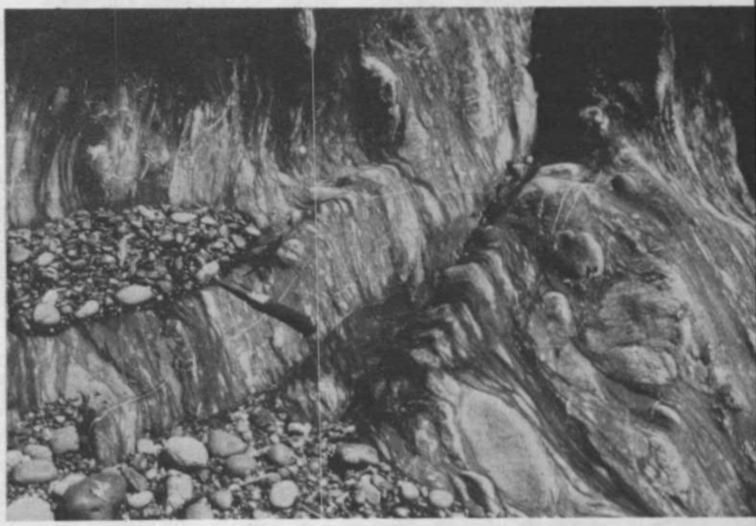


Figure 24. Intensely sheared flysch-type sedimentary rocks, south side of Outer Bay, Lopez.–Rounded light colored rocks were originally sandstone beds that fractured during shearing. Dark colored material is shale.

Volcanic Rocks

Volcanic rocks are among the most easily recognized of the bedrock lithologies. Their most obvious feature is "pillow structure" (Fig. 25).

Figure 25. Pillow lavas, Chadwick Hill, Lopez.–Pillows formed by submarine eruption. Outer margins of pillows were once volcanic glass. Small holes were gas vesicles which formed when lava was still molten.

The pillow lavas, or, more appropriately, pillow basalts, formed as a result of eruptions of lava from submarine volcanoes. As hot lava came in contact with cold sea water the lava fragmented into pillows which continued to move downslope as plastic blobs of lava with about the consistency of taffy. When a pillow came to rest it was usually soft enough so that its bottom surface assumed the shape of the underlying surface. By recognizing how pillows form, geologists can usually tell a right-side-up pillow from one that has been turned upside down by folding.

Pillows range from fist size to five or six feet in diameter. Some astonishing thicknesses of pillow lavas accumulated: Chadwick Hill, over 450 feet high, is composed entirely of pillow lavas as is Davis Head, most of Sparry Peninsula, the south end of Decatur Island, and other areas.

The pillow basalts have been metamorphosed, and many of the minerals which were originally present have been destroyed. The original texture, however, is often preserved. As pillows first form the outer margin is converted to volcanic glass at the contact with cold sea water. Although the glass has altered to other minerals, the relic glassy margin can often be recognized as a distinct rim around the pillow. Also, many pillows have small holes near their margins (vesicles) that are the remains of gas bubbles that formed in the lava due to release of pressure when the lava was erupted. Some of the vesicles are filled with low grade metamorphic minerals including aragonite pumpellyite, and chlorite.

Other kinds of volcanic rocks are sometimes encountered, such as dikes (small intrusions) of diabase, breccias (fragmented volcanic rocks), and tuffs (volcanic ash deposits). Pillow lavas are certainly the most common, however. Thin beds of linestone and red chert (jasper) occasionally accumulated between eruptions of pillow lavas.

The age of this unit may be Late Cretaceous or younger. Danner (1966) claims to have found probable Late Cretaceous microfossils in sedimentary rocks interbedded with pillow basalt at Richardson, Lopez Island. The same fossils were examined by a paleontologist affiliated with the Canadian Geological Survey who states they are "Late Cretaceous or younger" (Jan Muller, personal communication). Attempts are being made to find additional fossils at this site. Should the "Late Cretaceous or younger" age be confirmed, it is reasonable to suggest that the volcanic unit correlates with the Crescent Formation, which is widespread on the north and east sides of the Olympic Peninsula, and the Metchosin Formation on Vancouver Island.

Plant-bearing Sandstones and Conglomerates

Sandstones and conglomerates with plant fossils and coal beds occur on the north ends of Lopez and Decatur Islands and on James Island.

Figure 26. Conglomerate from plant-bearing sandstone and conglomerate sequence, probably on James Island.–Clasts are relatively unsorted for size and composition.

These rocks are different from the flysch-type sedimentary rocks described above. Most of the conglomerates, which make up the bulk of the unit, are very poorly sorted for size and give the impression of virtually having been dumped into the basin of deposition (Fig. 26). Many are probably mudflows. The interbedded sandstones commonly show graded bedding suggestive of deposition of turbidity current in deep water.

Figure 27. Coal bed in plant-bearing sandstone and conglomerate sequence, northwestern Decatur Island. Coal has little strength and deforms easily under stress. Sandstone beds overlie and underlie the coal.

Fossil twigs and branches occur widely in these rocks; sometimes plant remains are present in sufficient quantity to make coal seams (Fig. 27). One coal bed two feet wide was found on Decatur Island. Considering that coal is very easily eroded one might expect more coal to be present than actually crops out.

Although coal is not normally deposited in a deep water marine environment, there are some marine environments, such as on a delta, where abundant organic material would be expected. The presence of rapidly deposited sandstones and conglomerates further suggests deposition near a large source of terrigenous sediment; the base of a large marine delta seems to fit the picture nicely.

There are a great many lithologies present as pebbles and sand grains, including cherts, volcanics, plutonics, metamorphics, limestone, and shale chips. One conglomerate bed on Decatur Head is probably a volcanic mudflow.

Although plant-bearing sandstones and conglomerates are not as penetratively deformed as the flysch unit, shearing is commonly observed and the rocks have undergone low-grade metamorphism to the prehnite-pumpellyite facies.

Good exposures of plant-bearing sandstones and conglomerates are found at Upright and Humphrey Heads (Fig. 28), Lopez, on the north and northwest sides of Decatur Island, at Decatur Head, and around James Island.

Figure 28. Humphrey Head is composed of plant-bearing sandstones and conglomerates. The remains of twigs and branches are seen in rocks on the floor of the rock quarry on the right side of Humphrey Head. Note the spit connecting Humphrey Head with Lopez (right), Spencer Spit, and Frost Island (upper left).

Using the fission track method, a number of igneous cobbles in the conglomerate at Decatur Head were dated. The youngest cobble gives an Eocene date. This may mean either that the cobble was formed in the Eocene and the unit is Eocene or younger, or, more likely, that the zircon "clocks" were re-set by prehnite-pumpellyite metamorphism at the Early Tertiary after the unit was deposited. Until fossils are found the age of this unit must be regarded as unknown.

Serpentinite

A few small widely scattered outcrops of serpentinite occur in fault zones on many of the islands. Exposures are usually not very good, because serpentinite is easily eroded. It is recognized by its blue-black color, its shiny appearance, and its slippery feel. Serpentinite is thought to be derived from deep within the earth's crust; its presence probably indicates a substantial amount of movement along faults. The largest outcrop of serpentinite occurs on the northeast side of Blakely Island.

Water-bearing Characteristics Of The Bedrock

The bedrock underlying the southeastern San Juans is so thoroughly cemented that most rocks have little, if any, porosity or permeability. The pores are plugged and groundwater usually occurs only in joints (cracks) and fractures in the rocks. Some water may exist at contacts between different kinds of rocks, such as between a sandstone and conglomerate. The goal of the driller is to intersect a joint, fracture zone, or contact with a well. Unfortunately, there is no very good way of predicting how far down this will be. This explains why it is sometimes possible to drill considerably below the water table before encountering water.

In spite of this, the bedrock is generally a reliable producer of small quantities of water (a few gallons per minute), which is usually adequate for single residences. The adequacy of a marginal well can be increased, of course, by installing a storage system.

Drillers logs for 29 wells drilled in the bedrock on Lopez, Frost, Center, and Long Islands were analyzed. (No logs for bedrock wells on Decatur or Blakely were available). Of these, 11 wells were drilled in greenstones, 11 in flysch-type sedimentary rocks, 6 in volcanic rocks, and only one in plant-bearing sandstones and conglomerates. In view of the nature of the bedrock melange, there is no guarantee, of course, that wells starting out in a particular lithology will end in the same lithology, although most of the larger blocks are probably at least hundreds of feet thick.

Data on bedrock well depths are shown in Table 1. The important point to note is that the average bedrock well is in the range of 180 to 240 feet deep, regardless of rock type or whether the well was started in surficial sediments or bedrock. A number of wells were drilled through a considerable thickness of surficial sediments before finally encountering water after penetrating the bedrock. (One well went through 285 feet of surficial sediments before water was found in volcanic bedrock.)

The *amount* of water seems to vary considerably with rock type. Although drillers' logs are reliable only for very general estimates of the well yield, the estimates are invariably higher for wells drilled in greenstones and volcanic rocks than they are for wells drilled in flysch-type sedimentary rocks. This difference is probably due to the lack of good joints and fractures in rocks with shale.

With the exception of one well, there is no information on the water-producing characteristics of the plant-bearing sandstones and conglomerates. One cannot help but be impressed, however, with the water that can be seen coming from fractures in this unit on the north side of Decatur Island. Since these rocks contain little shale, they are probably comparable to greenstones and volcanic rocks in their ability to produce water.

Rock type	*No. of wells*	*Average depth to bedrock (ft)*	*Depth in Bedrock (ft)* Average	*(ft)* Range	*Total Depth (ft)* Average	Range
Greenstone	11	11	190	41-405	201	75-414
Flysch	11	14	227	35-475	241	50-475
Volcanics	6	106	71	10-242	177	60-295
Plant-bearing rocks	1	6	77	-	83	-

Table 1. Well depths compared to rock types for 29 bedrock wells on Lopez, Frost, Center, and Long Islands.

During the summer of 1974 a well was drilled into flysch-type sedimentary rocks, apparently mostly shale, to a depth of 382 feet without encountering appreciable water. The shale seemed to be fractured so finely that water couldn't penetrate the rock even though the bottom of the well was far below the water table.

Figure 29. Center Island with Decatur Island in the background.–A possible groundwater shortage may exist on Center Island if development proceeds to its maximum potential.

A potential water problem exists on Center Island (Fig. 29), an island of about 180 acres underlain by flysch-type sedimentary rocks between Lopez and Decatur Islands. All but about 40 acres are platted into 180 recreational homesites; of the remainder, four acres were recently purchased by the State for the possible development of a campground. Practically all of the groundwater must come from bedrock.

The well used by the recreational development community in the summer of 1974 was approximately 450 feet deep and yielded five gallons per minute or less. The water had a salty taste, and pumping was restricted to about an hour per day for fear of further salt water intrusion. Other wells were drilled in the summer of 1974 to depths of 280 feet, 318 feet, and 400 feet, with estimated water yields of three gallons per minute or less. One of these was drilled as a community well by the development, and the others were drilled by private individuals within the development who were apparently not satisfied with the quantity or quality of water available from the community wells.

Only about one-sixth of the lots on the development have houses built on them, and the campground is undeveloped. It seems clear that development on Center Island could easily outstrip the supply of groundwater (if it has not already done so), and that other sources of water may have to be found if development is to proceed to what is now planned.

ORIGIN OF THE MELANGE IN THE SOUTHEASTERN SAN JUAN ISLANDS

Having briefly described the major rock types comprising the bedrock, one is then in a position to ask "What does it all mean? How did the rocks get where they are now?"

Any answer to these questions should be preceded by a word of caution: this is where one must separate fact from interpretation. To begin, three facts should be restated. First, all the bedrock lithologies are sheared. Shearing usually takes the form of tiny partings (foliation) in rocks, but a variety of other structures, such as brecciated zones, disrupted sandstone beds, and contacts between rock types that are not parallel to bedding, may also be present. Some of the best examples of shearing can be seen in the flysch-type sedimentary rocks because shale has very little strength and shears easily. It flows around more brittle rocks like sandstone and chert. Fig. 30 shows part of a coherent block of volcanic material which appears as an island in a sea of sheared shale.

Second, the geologic map (Plate 1) shows that large,

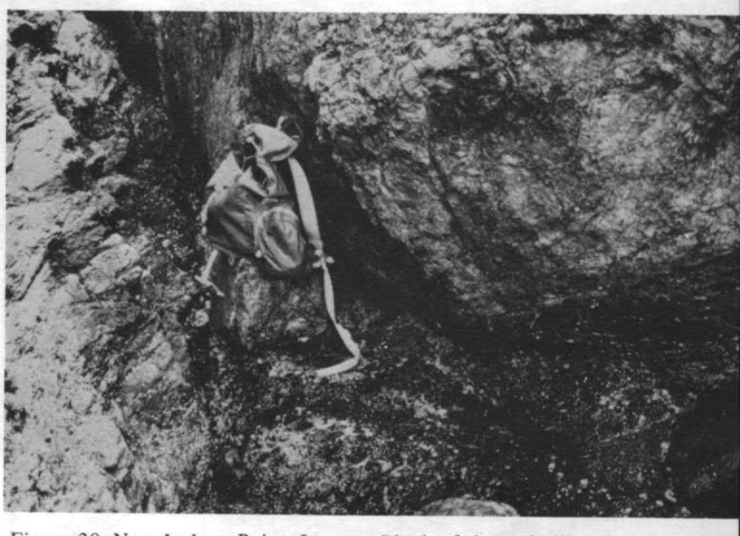


Figure 30. Near Iceberg Point, Lopez.–Block of sheared pillow lavas (upper right) in a matrix of sheared black shale.

Figure 31. Sheared contact, Johns Point, Lopez.–Folded bedded chert (left) in contact with sheared pillow lavas (right).

relatively coherent blocks of rocks occur almost randomly. On a slightly smaller scale than the map, Fig. 31 illustrates a large block of bedded chert in fault contact with volcanic rocks. There is no easy or obvious way to connect the blocks of similar rock type by either folds or faults to make them "match up," as geologists usually are able to do. Interestingly enough, on the south coast of Lopez, even though the foliation and bedding generally strike northwest and dip to the northeast, some blocks have been found that are right side up, but many others are upside down. This does not seem to be due to folding but, rather, to a 180° rotation of some blocks in the process of faulting and shearing.

Third, the zones between the large blocks are intensely sheared and commonly consist of smaller blocks–from room size to microscopic size–all sheared together. On the western tip of Johns Point, Lopez (Fig. 32), greenstones, flysch-type sedimentary rocks, volcanic rocks, and cherts are all sheared together on a scale much too small to map on the geologic map. Some geologists who have visited Johns Point are inclined to think that the contacts between rocks types are primarily depositional (bedding), slightly modified by faulting. These divergent views (sheared contacts vs. depositional contacts) are equally difficult to prove, and one's philosophy in interpreting such contacts pretty much determines whether one believes the bedrock of the southeastern San Juans is a melange or not.

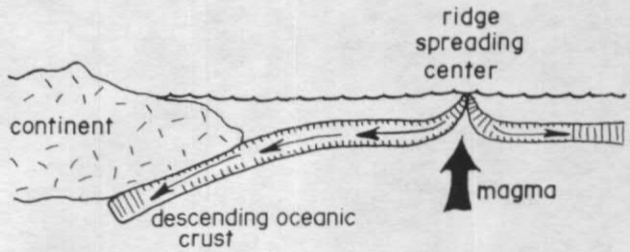
Figure 32. Johns Point, Lopez.–Many fine examples of sheared contacts between different rock types are found at Johns Point. In the background behind Johns Point are Mackaye Harbor, Mud Bay, Rosario Strait, and Fidalgo Island.

In my view, there are two strong arguments for believing that most of the contacts are tectonic, caused by shearing. Shearing is an extremely common deformational structure in all rock types. Sheared contacts that are oblique to bedding are not disputed; only those that parallel bedding are. It would seem unusual if shearing directions fortuitously avoided bedding directions, which, in most cases are probably the zones of greatest weakness in rocks–and those most likely to shear.

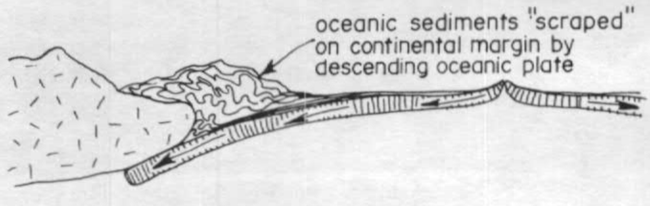
Second, it is extremely difficult to imagine a depositional environment in which flysch-type sedimentary rocks, pillow lavas, and greenstones could be deposited in alternating "beds," some no more than a fraction of an inch thick. From what we know of modern environments, turbidites and pillow lavas are each commonly deposited in extremely thick sequences, and though they are sometimes interbedded, they are not likely to occur in alternating thin beds. The greenstones, of course, simply had to be justaposed by faulting as they are metamorphic and were not deposited like the other rocks were.

How Did It All Happen?

We know that the crust of the ocean basins is being created by spreading along ocean ridges, and that oceanic crust is being consumed at the margins of the Pacific Ocean by a process called subduction. One effect of this spreading of the sea floor is to cause the continents to change their size, shape, and position relative to one another. Although sea floor spreading operates very slowly, over long periods of geologic time its effect on the earth's surface has been profound.



It is possible that the process of subduction created the chaotic mess of materials in the bedrock of the southeastern San Juan Islands. We have independent evidence from other work that the west coast of North America represents a collision zone between Pacific Ocean crust and North American continental crust which are moving toward each other. Other melanges on the west coast of Vancouver Island, on the Olympic Peninsula, in Oregon, and in California have been interpreted this way.



In a collision between a continent and an ocean basin one would expect fragments of both to be present in the collision zone. The greenstones, volcanic rocks, and flysch-type sedimentary rocks are probably oceanic crust and overlying volcanic and sedimentary material. The plant-bearing sedimentary rocks were probably deposited in a marine environment closer to the continent. We don't know where these rocks originally formed, nor do we know the precise process by which they were brought together.

During subduction the oceanic crust descends downward beneath the continent and stuffs the region along the edge of the continent with oceanic crust and deep sea materials brought in with the incoming crust, together with material from the continent. The effect of this "stuffing" on the materials is to create a melange of sheared blocks of various sizes and shapes–exactly like those found on Lopez, Decatur, and Blakely Islands.

If this interpretation is true, the melange in the southeastern San Juans probably represents the downturn of an ancient piece of oceanic crust, most of which was long since consumed.

The age of the melange–the time of the collision–is unknown. Once we learn the ages of the rocks in the melange we will have a good start in answering this question. In the meantime we can speculate that the fission track ages may be dating a metamorphic event that occurred during the Cretaceous or Early Tertiary, and that the metamorphism may have been caused by the collision.

Regardless of when it happened, a most interesting relic, the San Juan Islands, was left behind which was shaped and modified millions of years later by glaciers. The geologic puzzle is complex, but some of the pieces seem to be fitting together.

PART IV

"SURFACE WATER RESOURCES OF SAN JUAN COUNTY"

By William E. Dietrich

CLIMATE

General

The climate of San Juan County is typified by relatively short, cool, dry summers and mild, moderately wet winters. It is best understood by considering the regional setting of the county.

During the winter an almost continuous series of low pressure storms drift across the Pacific Northwest from the Pacific Ocean. Moisture-laden clouds moving inland from the southwest are forced upward by the Olympic Mountains with great quantities of precipitation being released during the ascent. On the leeward side of the mountains, where the San Juans lie, much less rain falls because the air is descending and warming. This "rainshadow effect" has a pronounced influence on precipitation across the San Juans (Figure 1). Rainfall at the southern edge of Lopez Island and San Juan Island is several inches less than it is at Upright Head near the northern tip of Lopez. Most of the rainfall in the San Juans (60%) occurs during winter months. Winds during winter are primarily from the south, southwest and southeast. Commonly, freezing temperatures occur for a few days in mid-winter when cold arctic air from the northeast moves down the Frazer River Valley and across the islands.

The dry, clear weather of summer is the result of the semipermanent "Pacific High" extending northward and blocking the invasions of low pressure storms into the region. Cool winds associated with summer high pressure generally emanate from the west and southwest. The maritime temperature is maintained by these cool breezes and the area is protected by the Cascades from warm, dry continental air.

Availability of Weather Data

Currently the only official weather station in San Juan County is Olga 2SE, on Orcas Island. It was established in 1890 and has been operated the entire time by the Willis family. Data collected at this weather station have proven invaluable in climate studies of the Northwest. Other official weather stations in San Juan County existed at Richardson (1949-58) and at Friday Harbor (1931-49). Eight weather stations on islands in British Columbia were used to better define the regional precipitation distribution. Data were obtained from several weather stations operated by individuals on the San Juan Islands. Records at each of these stations were compared by statistical methods to Olga data to determine usefulness. Most of the records were found to be of value.

Estimations of precipitation quantities were improved through use of measured runoff from each gaged watershed. This method, which is explained in Appendix E, allowed a more detailed analysis of precipitation variation across the county. However, it should be emphasized that because of a lack of previous stream gaging records and the limited amount of weather data, most values reported here for precipitation and runoff are simply [best] estimates. (Tables 1, 2; Figures 2, 3, 4).

TABLE 1: Official and Unofficial Weather Stations in or near San Juan County

In San Juan County	*Length of Record*
Olga 2SE (official–Willis Family)	1890-present
Friday Harbor (official)	1931-1949
Richardson (official)	1949-1958
Upright Head (unofficial–Phoebe Blalock/Frank Church)	1963-present
Friday Harbor (unofficial–Joe Long)	1966-1968
Little Summit (unofficial)	1967-present (summer months only)
East Sound (unofficial–Joe Long)	1968-present
Friday Harbor (unofficial–Ralph Rich)	1970-present
Briggs Pond (unofficial–National Park Service)	1972-1973
English Camp (unofficial–National Park Service)	1973-present
S.W. San Juan Island (unofficial–Mrs. W. Heindenreich)	1973-present
Local Weather Stations (official)	
Anacortes	
Bellingham	
Coupeville	
Elma	1941-1970
Everett	
Port Angeles	
Port Townsend	
Sedro Woolley	
Sequim	

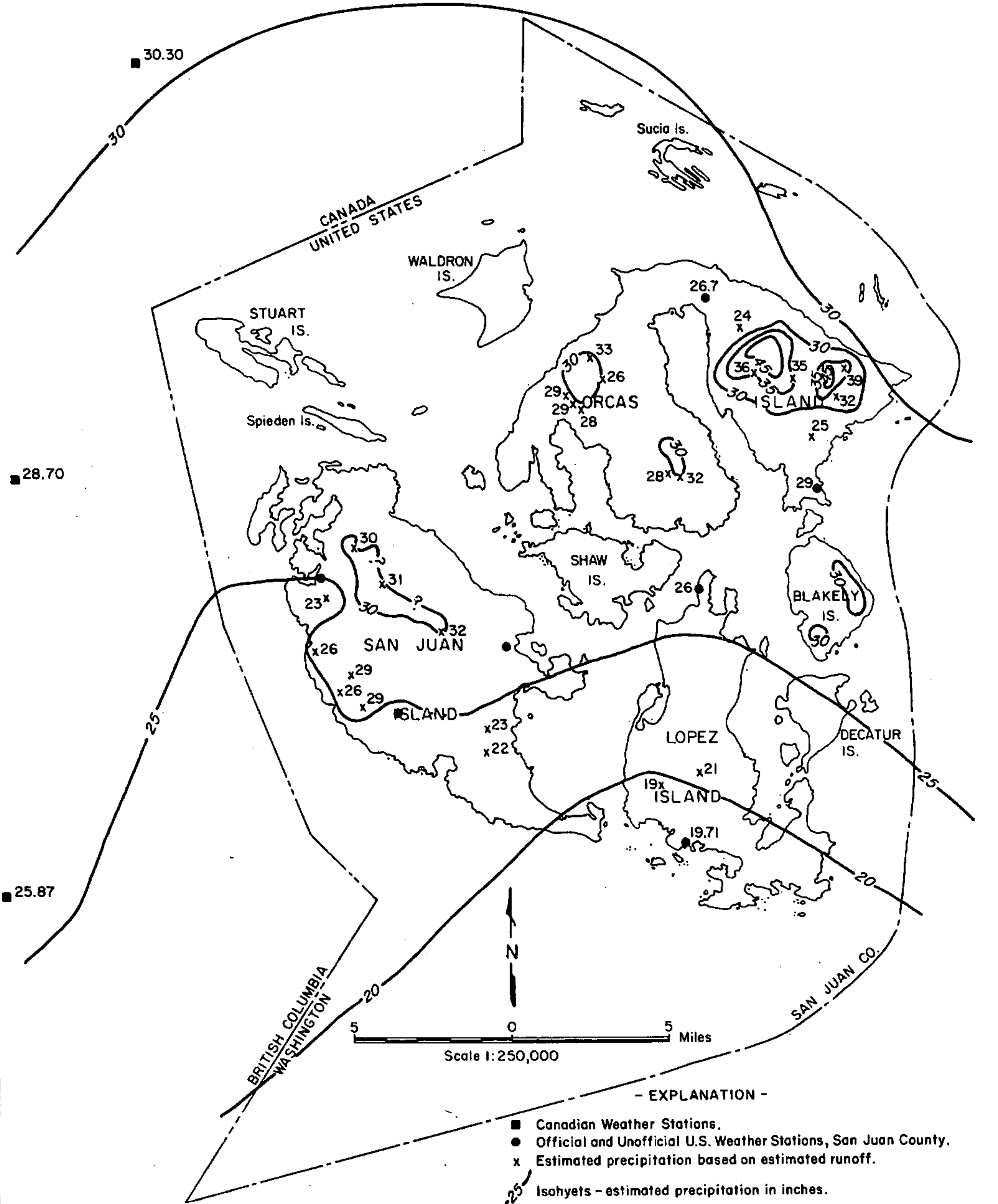


Figure 1. ESTIMATED MEAN ANNUAL PRECIPITATION.

British Columbia Weather Stations (official)

Galiano Island	
Ganges, Saltspring Island	
James Island	
Pender Island	1941-1970
Sandwich Dam Observatory	
Victoria, Ganzola Heights	
Victoria, International Airport	
Vesuvious, Saltspring Island	

TABLE 2. Precipitation, Olga 2SE

	Amount (inches)	*Period of Analysis*
Mean water year	29.44	1891-1973
Mean calendar year	29.22	1941-1970
Greatest water year	40.02 (1894)	1891-1973
Greatest calendar year	37.89 (1917)	1891-1973
Least water year	15.95 (1929)	1891-1973
Least calendar year	15.09 (1929)	1891-1973
Greatest 1 day rainfall	3.40 (1/1935)	1890-1965
Average number days of precipitation per year	133 (36%)	

Precipitation

Figure 1 shows the estimated mean annual precipitation in San Juan County. It was constructed from data sources listed in Table 1, and from the results of miscellaneous flow measurements in 1974 (see Appendix E for explanation of the technique used to estimate precipitation from stream data). Annual precipitation varies greatly across the islands, generally increasing from south (19 inches) to north (30 inches), and with elevation from 19 inches at the low-lying southern end of Lopez, to over 45 inches in the Mt. Constitution area. As shown in Figure 2, December is usually the wettest month and July the driest. Table 2 lists general information about rainfall characteristics at the Olga 2SE weather station and Figures 3, 4, and 5 show graphically the probability of occurrence of precipitation at the Olga weather station.

In Figure 6, estimated average annual precipitation for the various watersheds in which flow measurements were made is plotted against mean elevation of the watershed. Two watersheds (SJ-10, 0-11) from which gaging records were poor were deleted from Figure 6. Mean elevation is calculated by adding the elevation of the highest ridge to the elevation of the gaging station and dividing by two. This figure shows that above about 300 feet precipitation increases with elevation and that the rate of increase steepens with higher elevations.

Temperature

The San Juan Island's geographic setting results in mild temperatures throughout the year. The surrounding waters and Pacific sea breezes moderate air temperature extremes by causing cooling during the summer and warming during the winter. In addition, the islands are protected by the Cascade Mountains from the extreme temperatures of the continental air masses. With the exception of Port Angeles, Stampede Pass, and Clallam Bay stations the Olga station has lower mean temperatures for July and August than any other station in Washington. Table 3 and Figure 7 show means, extremes and probability of occurrence of temperatures at Olga 2SE. Mean monthly temperatures for Olga and other stations are shown in Figure 2 to indicate general variations through the seasons and across northern Puget Sound.

Climatic Trends

Since precipitation is the sole water input and temperature is the primary influence on water loss in the calculation of the water budget, it is essential to define climatic trends of temperature and precipitation.

Statistical analysis of the Olga 2SE weather data shows three significant trends in temperature and precipitation since 1891. The cumulative sum deviation chart (Figure 8) is made by plotting the cumulative difference between the mean value and yearly value. For example, mean annual water year precipitation for the water year period 1891-1973 is 29.44 inches. In water year 1892 total precipitation was 32.0 inches, 2.56 inches above the mean. In 1893 it was 32.65 inches or 3.21 inches above the mean, which when added to the 1892 deviation gives a total deviation of 5.77 above the mean for the two years. This procedure, carried through the entire record, has a final total deviation from the mean of zero.

TABLE 3 Temperature Data, Olga 2SE

	Temperature	*Period of Analysis*
Mean Annual Temperature	49.3°F	1941-1970
Warmest Month	59.6°F (July)	1941-1970
Coldest Month	38.3°F (January)	1941-1970
Highest Maximum Recorded (daily)	92°F (July, 1941)	1929-1958
Lowest Minimum Recorded (daily)	-8°F (January, 1950)	1929-1958
Average Cooling Degree Days	7	1941-1970
Average Heating Degree Days	5721	1941-1970
Growing Season		
Average number of days above	32°F=237 (1931-1960)	
	28°F=300	
	24°F=345	

From this chart it can be seen that from 1891 to about 1923 there was a trend toward increasing precipitation and decreasing mean temperature. From 1923 to 1946, there was a large decrease in precipitation and increase in temperatures, and since 1946 the trend has been toward increased precipitation and decreased temperatures.

This general climatic trend, particularly during the 1923-46 and 1947-73 periods, has been observed in several areas of the United States. At present, no valid hypothesis has been presented to explain this cyclic nature of climate. Yet, analysis of climatic trends is useful in determining the relationship between "mean" annual precipitation and

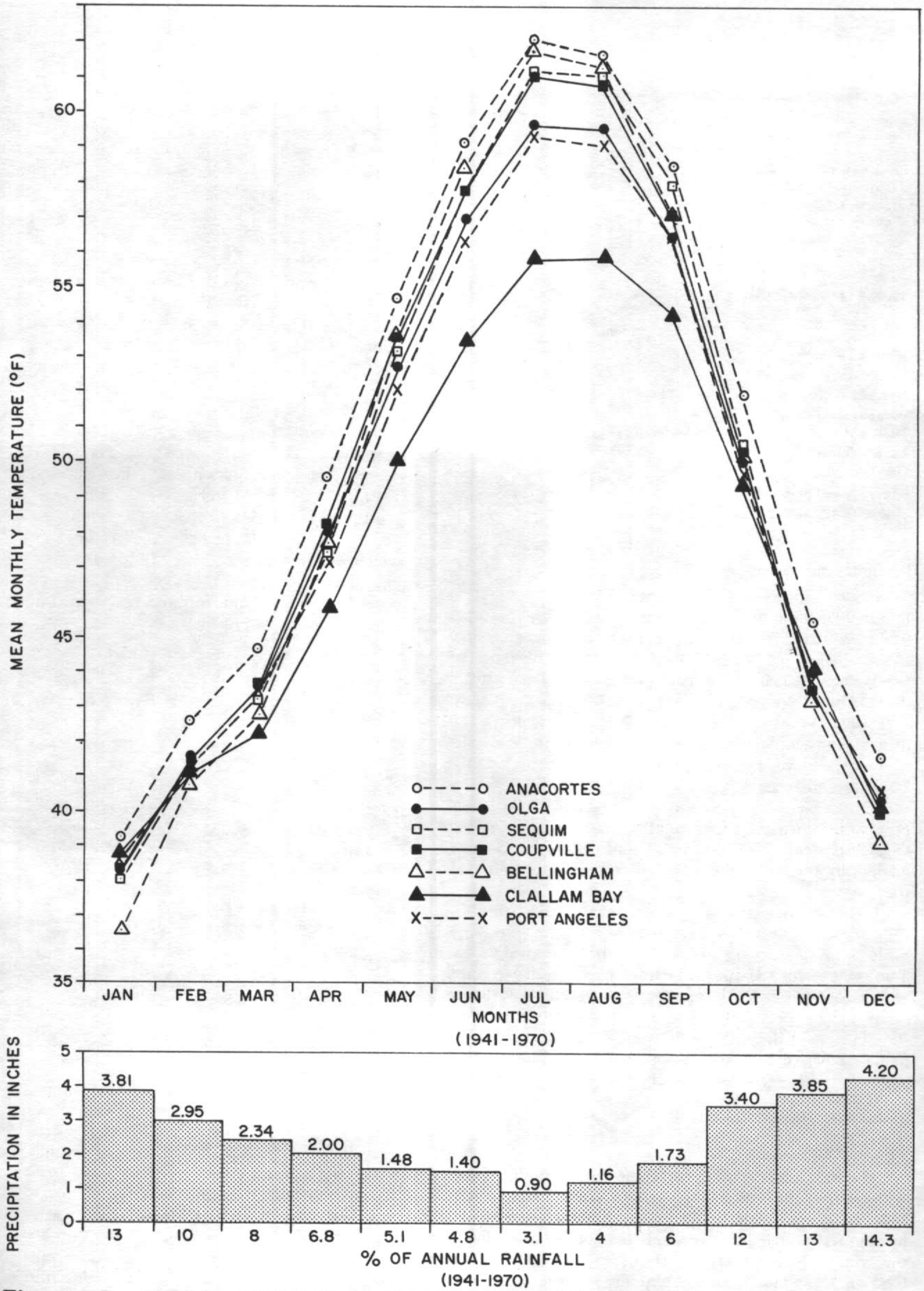
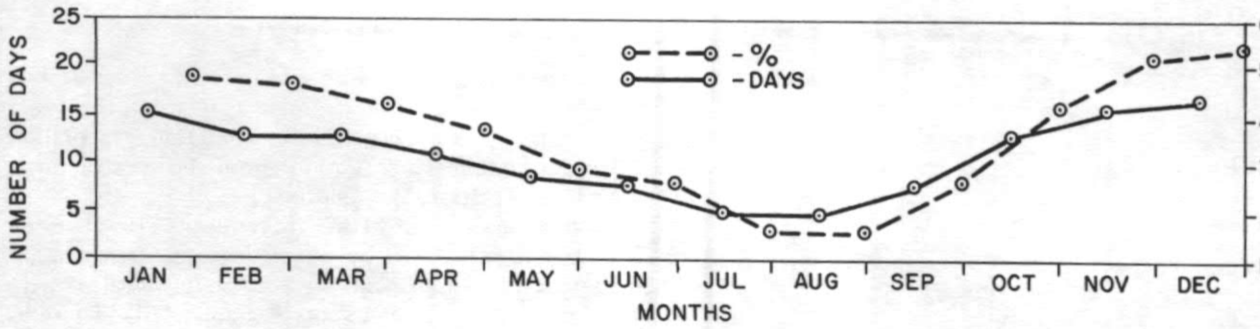


Figure 2. MEAN MONTHLY TEMPERATURE AT OLGA AND NEARBY STATIONS AND MEAN MONTHLY PRECIPITATION AT OLGA, (1941-1970).



FROM PHILLIPS, 1966

Figure 3. AVERAGE NUMBER OF DAYS WITH PRECIPITATION (≥.01 INCHES) AT OLGA

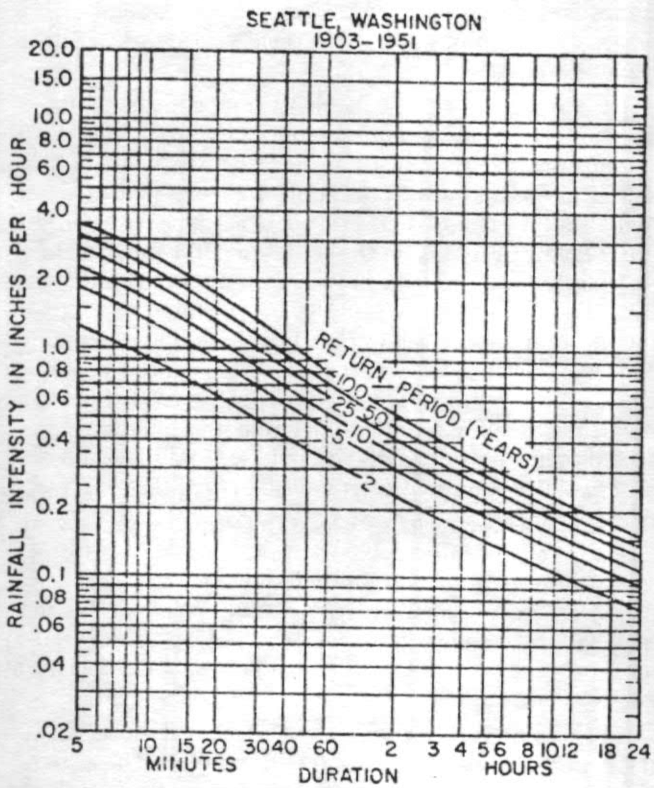


Figure 4. DESIGN RAINFALL INTENSITIES FOR SEATTLE AREA.

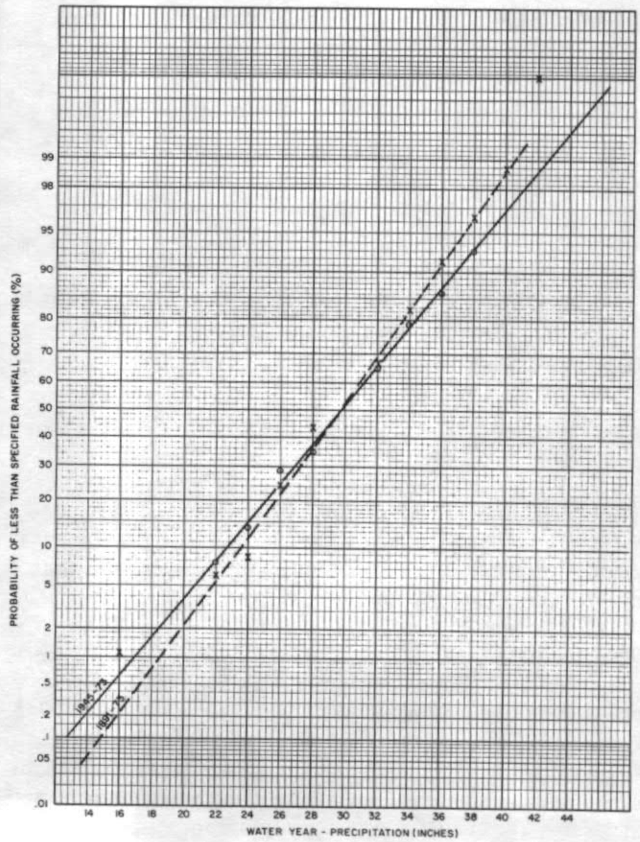


Figure 5. CUMULATIVE PERCENT FREQUENCY OF ANNUAL TOTAL PRECIPITATION AT OLGA 2SE.

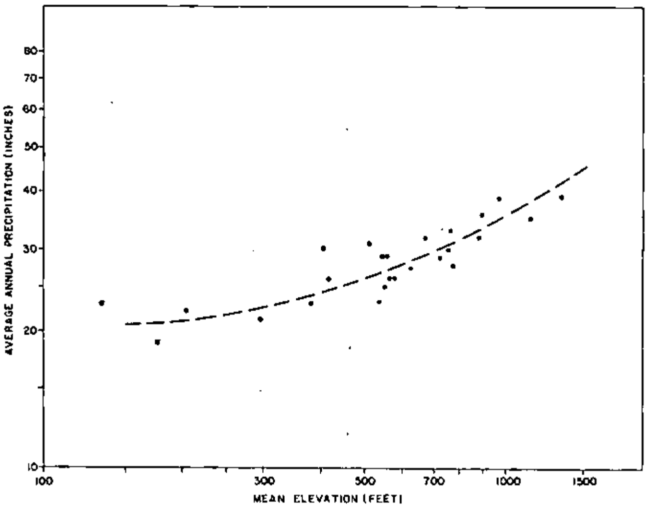
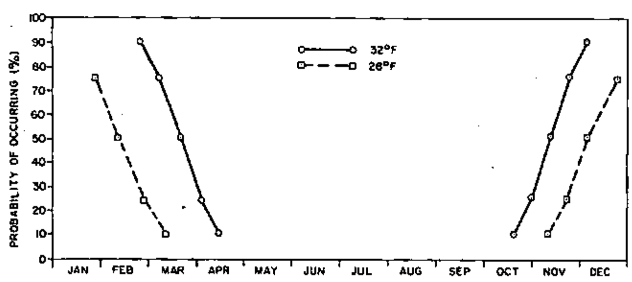


Figure 6. RELATIONSHIP BETWEEN ESTIMATED MEAN ANNUAL PRECIPITATION AND MEAN ELEVATION IN A WATERSHED.



FROM WEATHER BUREAU, 1959

Figure 7. PROBABILITY OF OCCURRENCE OF MINIMUM DAILY TEMPERATURES OF 28°F AND 32°F.

water supply. In Figure 8, it can be seen that the value for mean precipitation is a function of the length and interval of record used. Mean annual precipitation for the 1891-1921 period was 31.04 inches, for 1891-1945 it was 28.42 inches and for 1922 to 1945, 26.33 inches. Estimation of water supply potential based on 1891-1921 data would have over-estimated yield for the interval 1922-1945 by more than 4 inches.

At present, it appears that the climate in the San Juans is becoming cooler and wetter (Figure 8). This does not necessarily mean that the water supply potential is improving. Although mean precipitation (50% probability in a normal distribution) for 1945-1973 is slightly greater than the average for the entire period of record (1891-1973), the probability of severe droughts (less than 5% probability of occurrence) has also increased (Figure 5). For this reason, and because it is not known whether the cool and wet trend will continue, a runoff map for the year 1929 (Figure 9), the driest year of record, was constructed. This figure can be used to estimate minimum runoff from a watershed. This method is presented later in the text.

Water Budget

In evaluating the water resources of an area it is desirable to model the hydrologic system. The main elements of a water budget are precipitation, evaporation and transpiration (vaporization from plant structure), ground-water storage, and runoff.

A method devised by C.W. Thornthwaite (1957) can be used to estimate runoff by calculating evapotranspiration (evaporation and transpiration) from simple weather data and general soil characteristics. A graph of the Thornthwaite model (Figure 10) demonstrates that in the San Juans the most important loss in the water budget is evapotranspiration. At the Olga 2SE station, over 67% of the average annual precipitation returns to the atmosphere by this process.

Potential evapotranspiration is the total amount of water that could be lost by evaporation and transpiration. Actual evapotranspiration is the amount that is actually lost due to limitations of precipitation and water storage in the soil. In an average year at the Olga 2SE station, potential evapotranspiration for a soil with a 6-inch water-holding capacity in the root zone is 5.35 inches greater than actual evapotranspiration.

In an average year in the San Juans, actual evapotranspiration is greater than precipitation from mid-April through September, causing water to be depleted from the soil. This soil moisture utilization is the amount of water that can be removed from the soil depending on its water-holding capacity in the root zone. In Figure 10 three different values for water holding capacity in the root zone were used (2 inch, 6 inch, and 10 inch), representing about the mean and extremes in San Juan soils and vegetation. Two inches would be typical of thin soil mantling bedrock, whereas ten inches would be typical of thick sandy loam soils covered by a forest. Actual evapotranspiration varies according to the amount of precipitation and the root zone water-holding capacity (water availability) of the soils.

Soil moisture recharge begins in October when precipitation generally starts to exceed evapotranspiration. Deeper soil sections require more precipitation and greater time to complete the recharge process. Runoff predicted by this method would diminish to nothing after April, and would not start again until sometime between mid-October and late November.

Field observations indicate that runoff occurs la than April and usually earlier than December. The amoun of runoff is usually insignificant during the April to December period predicted by the Thornthwaite method (see hydrographs in Appendix D). Low flows between storms and during spring and fall, are derived from ground water discharge to stream channels. In the Thornthwaite method it is assumed that there is no net change in ground water storage. In figure 11 a graph has been plotted using the Thornthwaite method to predict yearly runoff from mean annual precipitation which occurs in the San Juan Islands. Due to loss from evapotranspiration, runoff ranges from less than 11% of 19 inches annual precipitation to about 45% of 40 inches annual precipitation.

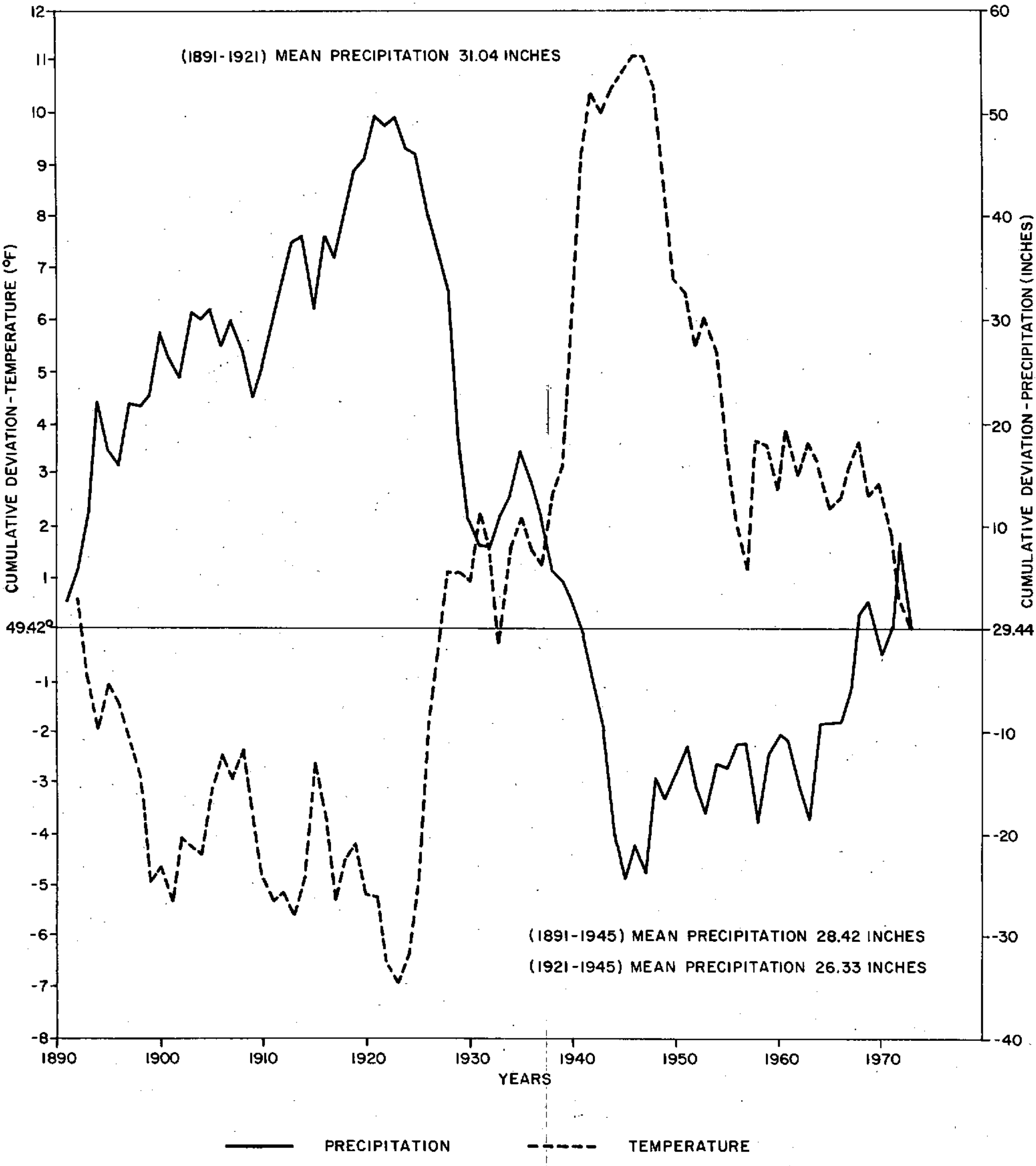


Figure 8. CUMULATIVE SUM DEVIATIONS FROM THE MEAN WATER YEAR-PRECIPITATION AND TEMPERATURE AT OLGA 2SE, (1891-1973).

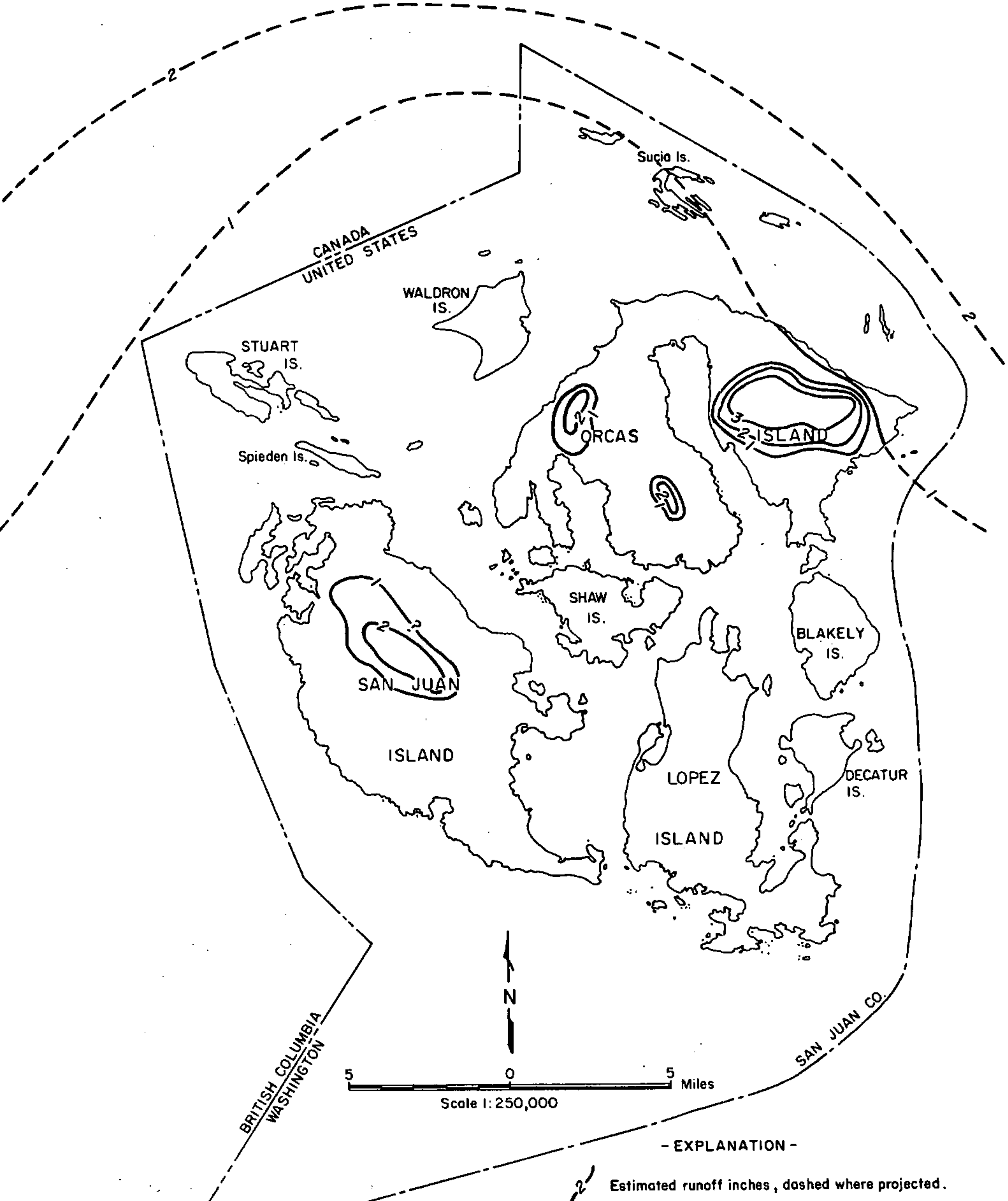


Figure 9. ESTIMATED 1929 RUNOFF (DROUGHT YEAR).

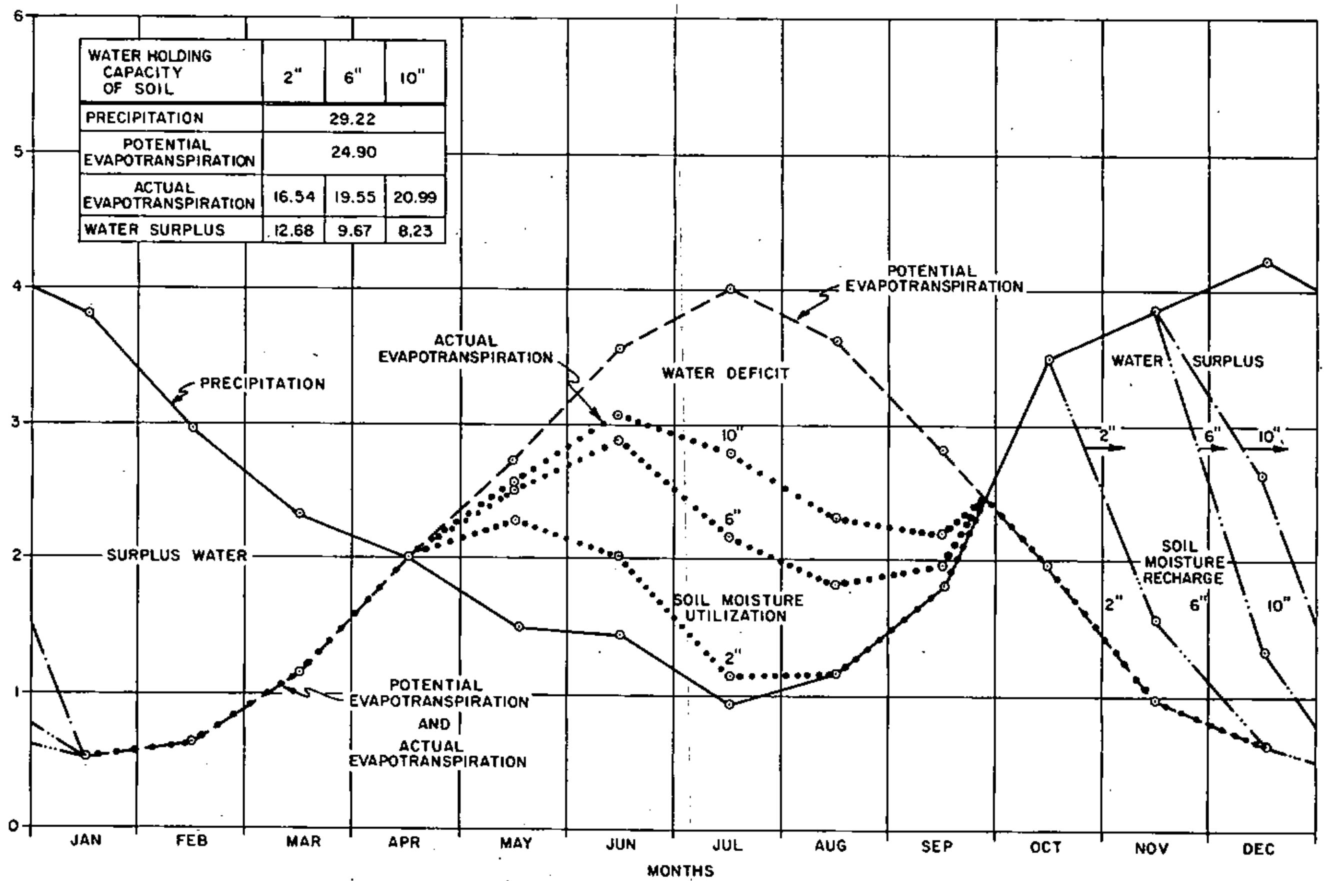


Figure 10, MEAN ANNUAL WATER BUDGET AT OLGA STATION.

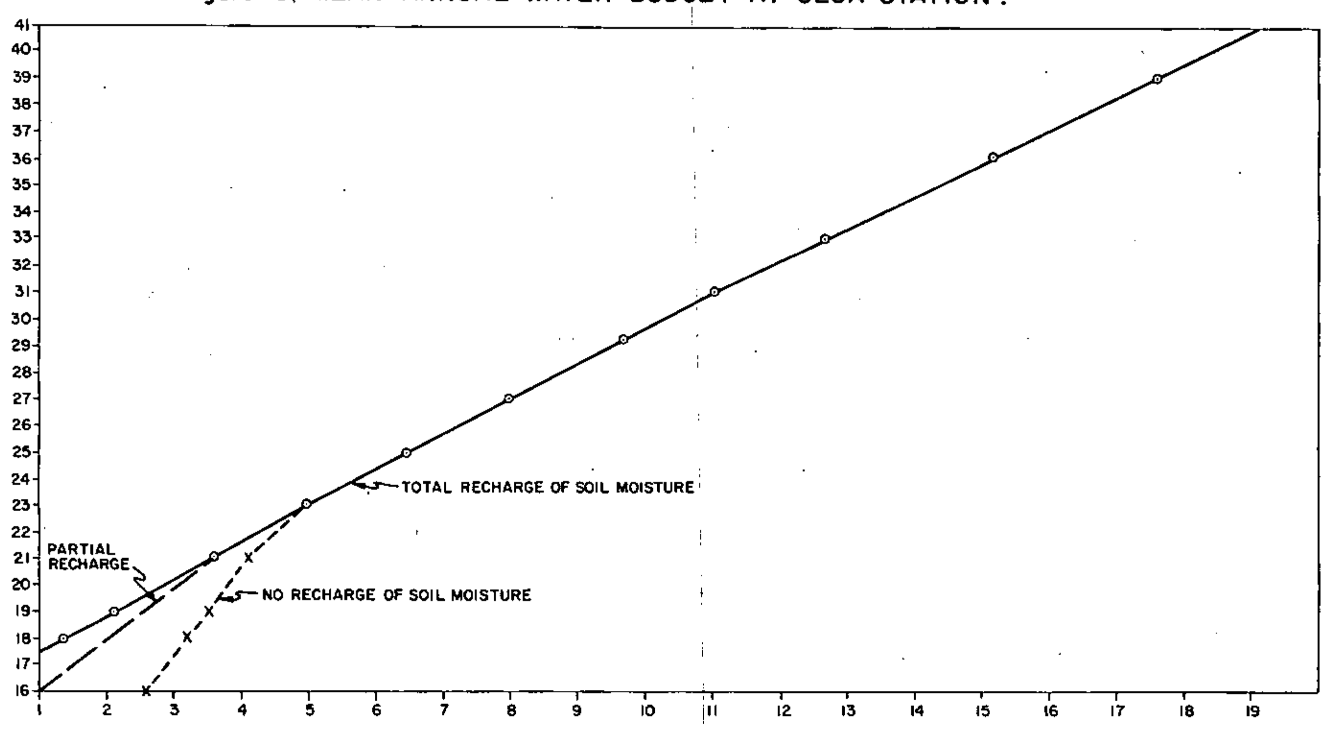


Figure 11. ANNUAL RUNOFF FROM PRECIPITATION AS PREDICTED FOR 6 INCHES WATER HOLDING CAPACITY SOIL BY THE THORNTHWAITE-MATHER METHOD.

The Thornthwaite method requires total recharge of soil water-holding capacity in the root zone before runoff in a watershed can occur. Although his model is incorrect, it can yield reasonable approximations of the average annual runoff for areas which receive high amounts of rainfall. In low precipitation areas, such as the southern San Juan Islands, storm runoff created by overland flow and return flow from small saturated areas near the channel occurs before most of the soil in the watershed is saturated (Dunne, 1970). The Thornthwaite method, by requiring total recharge of the soil moisture in the entire watershed, underestimates actual runoff from areas of low precipitation. If there were no recharge of the soil moisture, the runoff would be greater as shown in the graph. Based on field observations, the line of the graph which allows for partial recharge of the depleted soil moisture is probably most accurate.

In the drought years 1928-29, the driest on record, precipitation between October 1928 and September 1929 was only 15.94 inches at the Olga weather station. Actual evapotranspiration for soil with a 6 inch water-holding capacity was 14.44 inches, leaving 1.50 inches for runoff during the year. The mean annual runoff is 9.67 inches. Thus from this analysis, about 1/7 of the average stream discharge occurred. If a stream is to be used for water supply, the lower value should be considered in estimating its yield potential (see Figure 9).

SURFACE WATER RESOURCES

General

Although runoff in the San Juans is low compared to other areas in Western Washington, surface water ponding of runoff in lakes, reservoirs, and dug pits is the primary source of drinking, irrigation and stock water on the two largest islands, San Juan and Orcas. Lopez Island has many small dug pits which are quite satisfactory for storing irrigation and stock water. Blakely Island has abundant surface water storage in two large lakes. Because of space and topographic limitation on the smaller islands, ponded surface water is not greatly relied upon.

Availability of Data

Previous to this investigation, none of the streams in the San Juan Islands had been gaged and only a partial listing of the larger reservoirs and lakes had been compiled (Wolcott, 1965).

To evaluate potential runoff from the various watersheds of the San Juans (see Plate 3), a stream flow measuring program was initiated. A total of 28 streams (two on Lopez Island, ten on San Juan Island and sixteen on Orcas Island) were chosen for gaging during the 1974 calendar year. Two of the 28 streams, one draining Killebrew Lake on Orcas Island and one draining into Andrews Bay on San Juan Island, had staff gages installed which were read once daily by nearby residents. All of the major streams and most minor streams on the three large islands were measured once each month. Streamflows on the other islands were not measured because of time constraints. It is assumed, however, that conclusions drawn from the collected data can be applied to other nearby islands.

As most streams of the San Juan Islands are unnamed, each has been assigned a number. These numbers appear adjacent to the miscellaneous measurement stations in Plate 3 and are used in the text to refer to the stream, the station, and the drainage basin.

Most of the streamflow measurements were begun in January 1974 and were continued through December 1974. Results of analyzing these streamflow measurements are presented in Appendix D. The sizes and types of ponded surface waters (reservoirs, lakes, bogs, and dug pits) were determined from aerial photographs (scale 1" = 1000') flown in 1969. These were field checked when possible. A tabulation is contained in Appendix 3 of all surface water bodies in the San Juan Islands that were observed on aerial photographs or that were found during field investigations.

The Town of Friday Harbor supplied data on the withdrawal of water from Trout Lake, its source of water supply. This information was combined with precipitation data to model the availability and demands on this important water resource (see Trout Lake).

During the course of field investigations, interviews were conducted with residents which contributed valuable information about water use, general streamflow characteristics, and the water quality of streams. Where appropriate, this information was applied to watershed modeling.

Since there is a general paucity of precipitation records, particularly at higher elevations, and a similar lack of continuous long-term stream gaging records, estimates of mean and drought year runoff are subject to large errors.

Runoff Characteristics

Streamflow in the San Juan Islands is intermittent: The highest discharges occurring from December through February, and usually no flow occurring between late May or early June to late October or mid-November (see Runoff Hydrographs in Appendix D). Runoff is directly dependent upon precipitation which varies with distance from the Olympic Mountains (the rain shadow effect) and relative relief within individual watersheds. Estimated mean annual runoff is highest from the Mt. Constitution area of Orcas Island and lowest in low-lying areas of southern San Juan and Lopez Islands (Figures 12 and 13).

Basic Streamflow Data

Results of streamflow measurements for the year 1974 are tabulated (Appendix C) and presented in hydrographs (Appendix D). Shapes of the hydrographs vary according to total runoff. This variation is caused by the difference in the amount of fall and winter precipitation available to recharge moisture lost from soils in summer. The low amount of precipitation which occurs in the southern San Juans usually is not sufficient to initiate continuous streamflow until middle or late December, whereas, in the wetter areas to the north, and at higher elevations,

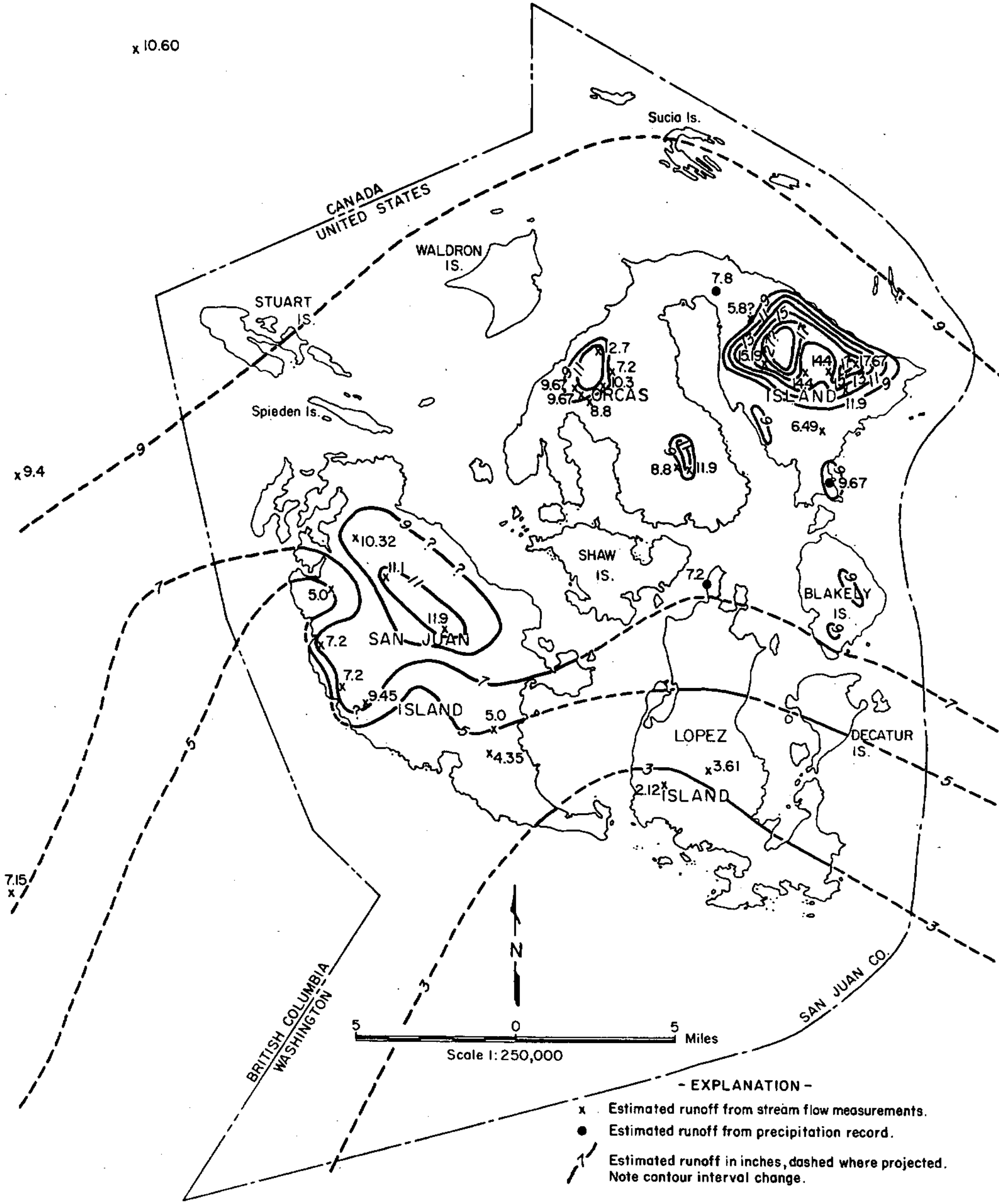


Figure 12. ESTIMATED MEAN ANNUAL RUNOFF.

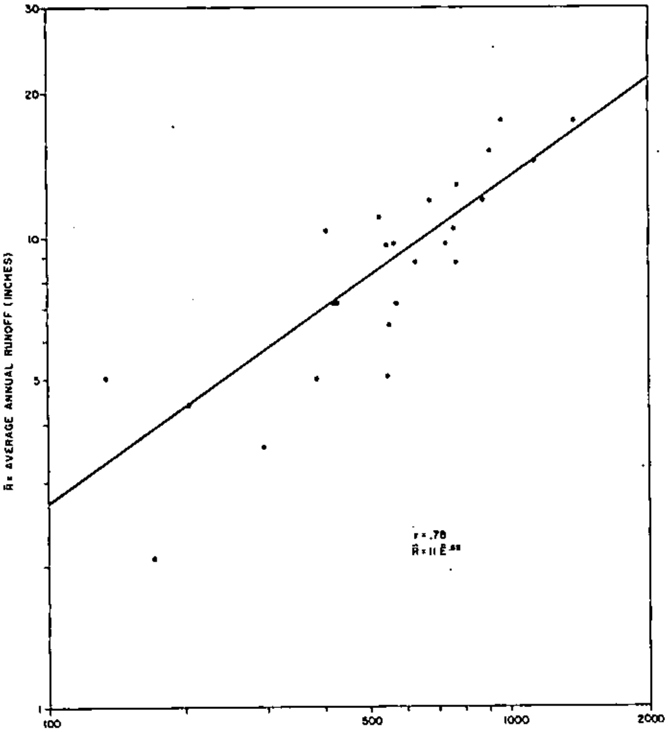


Figure 13. RELATIONSHIP BETWEEN AVERAGE ANNUAL RUNOFF AND MEAN ELEVATION IN WATERSHEDS WHERE STREAM FLOWS WERE MADE IN SAN JUAN COUNTY.

continuous runoff may begin in middle or late November.

Low flows in streams after June result from two sources: groundwater discharge and seepage from dams or bogs (Table 4). Less than 30% of the channels in which measurements were made in 1974 had flowing water in September. During this month only 3 streams exhibited flows in excess of 0.10 cfs (cubic feet per second). Such flows are probably typical of low flow conditions during average years.

Table 4

Sources of Sustained Summer Low Flow

Spring(s):		Dam(s) or Bog(s):
	L-2	0-6
	0-5	0-12
	0-11	R-2
	0-14	SJ-1
	OK-1-3	SJ-11A
	R-1	SJ-12
	SJ-6	

Surface Water Supply and Use

General

Almost all of the streams in San Juan County become dry by June and do not start to flow again until winter. As a result, reservoir storage is required to supply water during the dry season. Impoundments cover less than 1% of the surface area of San Juan County, ranging, on the larger islands, from about 0.3% of the area of Lopez Island to about 4% of the area of Blakely Island. In general, use of ponded water varies with each island. On Orcas Island, reservoir water is used primarily for domestic supply and recreation. On San Juan Island, it is used for irrigation, stock water, recreation, and domestic supply. Stored water on Lopez Island is used primarily for irrigation, stock water, and recreation.

Surface water supplies on the larger islands in San Juan County are described below. All water bodies are listed, according to location, in Appendix B.

ORCAS ISLAND

About one-third of the 57 square miles of Orcas Island is above 500 feet in elevation, and about 14% is above 1000 feet. As a result, watersheds on Orcas Island receive more rainfall and have better water supply potential than those on the other islands. A list of the "major" surface water bodies on Orcas Island (Table 5) shows that over 90% of the water stored in these reservoirs is in Mountain and Cascade Lakes. These two reservoirs supply water for the communities of Olga, Doe Bay, Rosario, and Rosario Heights. East Sound, the largest community on Orcas Island, is supplied by ground water.

TABLE 5. Major surface water bodies on Orcas Island

Water Body	*Estimated Surface Area (acre)*	*Est. Max. Storage Capacity (acre-ft)*	*Est. Avg. Annual Recharge from Precip. (acre-ft)*
Mountain Lake	100	8,800	2,200
Cascade Lake	170	4,600	4,000-5,000
Lake Martins	27	200	230
Killebrew Lake (Natural)	13.2	50	590
Day Lake	12	120	181
Twin Lakes (Natural)	11	70	576
Ayer Reservoir	10.3	135	164
Summit Lake	10	40	192
Utters Reservoir	10	98	374
Fonders Reservoir	9	70	165
Tureks Reservoir	7	40	30
Total	**459.5**	**14,223**	

+2200 acre-feet	:	runoff into Mountain Lake
- 350 acre-feet	:	evaporation from the lake
- 30 acre-feet	:	diversion by Doe Bay water users
Total 1820 acre-feet	:	discharge into Cascade Creek, if no net storage change in Mountain Lake

(1)

+1820 acre-feet : discharge from Mountain Lake
+ 600 acre-feet : runoff from Cascade Creek watershed below Mountain Lake
- 30 acre-feet : diversion by Olga water users
Total 2390 acre-feet : discharged below bridge in Moran State Park

(2)

x2390 acre-feet : a fraction (x) of the discharge in Cascade Creek which is diverted to Cascade Lake

if x equals ¾ then,

+1793 acre-feet : discharge into Cascade Lake from Cascade Creek
+3000 acre-feet : runoff from the rest of the Cascade Lake watershed
- 303 acre-feet : evaporation from the lake
- 50 acre-feet : approximate diversion for drinking water in Rosario area
Total 4440 acre-feet : average annual discharge into East Sound from Cascade Lake

(3)

or 1120 acre-feet : runoff in a drought year of 1% probability of occurrence.

Summit Lake, Mountain Lake, and Cascade Lake

These three lakes receive runoff from the region around Mt. Constitution, which is the wettest area in San Juan County. Summit Lake is formed by a small concrete dam at its southeast end. Water released from this reservoir flows into Mountain Lake. At the combination earthfill-concrete dam of Mountain Lake, Doe Bay water users divert approximately 30 acre-feet of water per year, but have water rights for 94 acre-feet per year. A five-inch pipe at the base of the dam discharges water into Cascade Creek. Just above the bridge which crosses Cascade Creek in Moran State Park, Olga water users divert about 30 acre-feet of water per year. They have water rights for 94 acre-feet per year. Most of the flow in Cascade Creek below this bridge is diverted by a dam, pipe, and cement canal to Cascade Lake. The Cascade Lake dam, constructed in 1884 about 64 years before Mountain Lake dam was built was originally designed to generate D.C. hydroelectric power (35-75 KW). G. and G. Geiser have water rights for 610 acre-feet of water per year from Cascade Creek for this purpose and domestic use. Approximate water balance in an average year for this system is:

The highest summer low flows in San Juan County occur at Keys Springs (OK-1–OK-3, Plate 3) located southeast of East Sound on Orcas Island. Discharge measurements made from July to December, 1974 are reported in Appendix C. In July through October, the combined outflow from the springs was about 190 acre-feet or about 60 million gallons.

Average annual runoff from OK-3, estimated by adding summer flow measurements, 190 acre-feet, to runoff from precipitation of about 13.2 inches or 340 acre-feet (Figure 13), is about 530 acre-feet.

SAN JUAN ISLAND

Of the lakes listed in Table 6, only Trout Lake, Briggs Pond and Lakedale Lakes are used to supply domestic water. Zylstra Lake, which on the average supplies about 300 acre-feet, is the most important irrigation water reservoir in San Juan County. About 400 acres of farmland in San Juan Valley are irrigated with this water.

TABLE 6. Major Surface Water Bodies on San Juan Island

Water Body	*Estimated Surface Area (acre)*	*Est. Max. Storage Capacity (acre-ft)*	*Est. Avg. Annual Recharge from Precip. (acre-ft)*
Sportman's Lake	66	500	2,000
Zylstra Lake	53	430	1,600
Lakedale Lake	50	400	250
Trout Lake	60	1,400	686
Briggs Pond	29	210	350
Woods Reservoir	18	180	50
Lawson Lake	12.5	177	70
Burton/Louthan L.	13.5	100	30
Hannas Lake	8	50	170
Heidenrichs Lake	6	70	100
Totals	301.7	2,859	5,506

Trout Lake Reservoir

Although smaller in size and capacity than Mountain or Cascade Lakes, Trout Lake, at present, is the most important surface-water resource for domestic water supply in the county. It supplies the Town of Friday Harbor and serves about half of the total population of San Juan Island.

Trout Lake is about 60 acres in surface area and has a storage capacity of approximately 1400 acre-feet. Based on yearly fluctuations in water level behind the dam (Figure 14), general runoff characteristics determined by measuring flow in nearby creeks and seepage from the reservoir itself, it is estimated that the average annual rainfall into the Trout Lake watershed is about 29.00 inches. Analysis of data obtained from water treatment plant reports of Friday Harbor by the Department of Social and Health Services showed that water demand by the 800 plus people it serves is presently about 540 acre-feet per year. This demand alone would cause about a 9 foot drop in the water level of Trout Lake. An estimated 104 acre-feet is lost to evaporation and 20 acre-feet is lost to seepage each year. Thus, the total loss from the lake is about 660 acre-feet per year, or eleven feet of drawdown (see Table 7). Average annual input into the lake from rainfall caught by the 1.32 sq. mile watershed above the dam, minus that lost to evapotranspiration, is 9.6 inches or 676 acre-feet which equals eleven feet of recharge. In an average year the loss from water use,

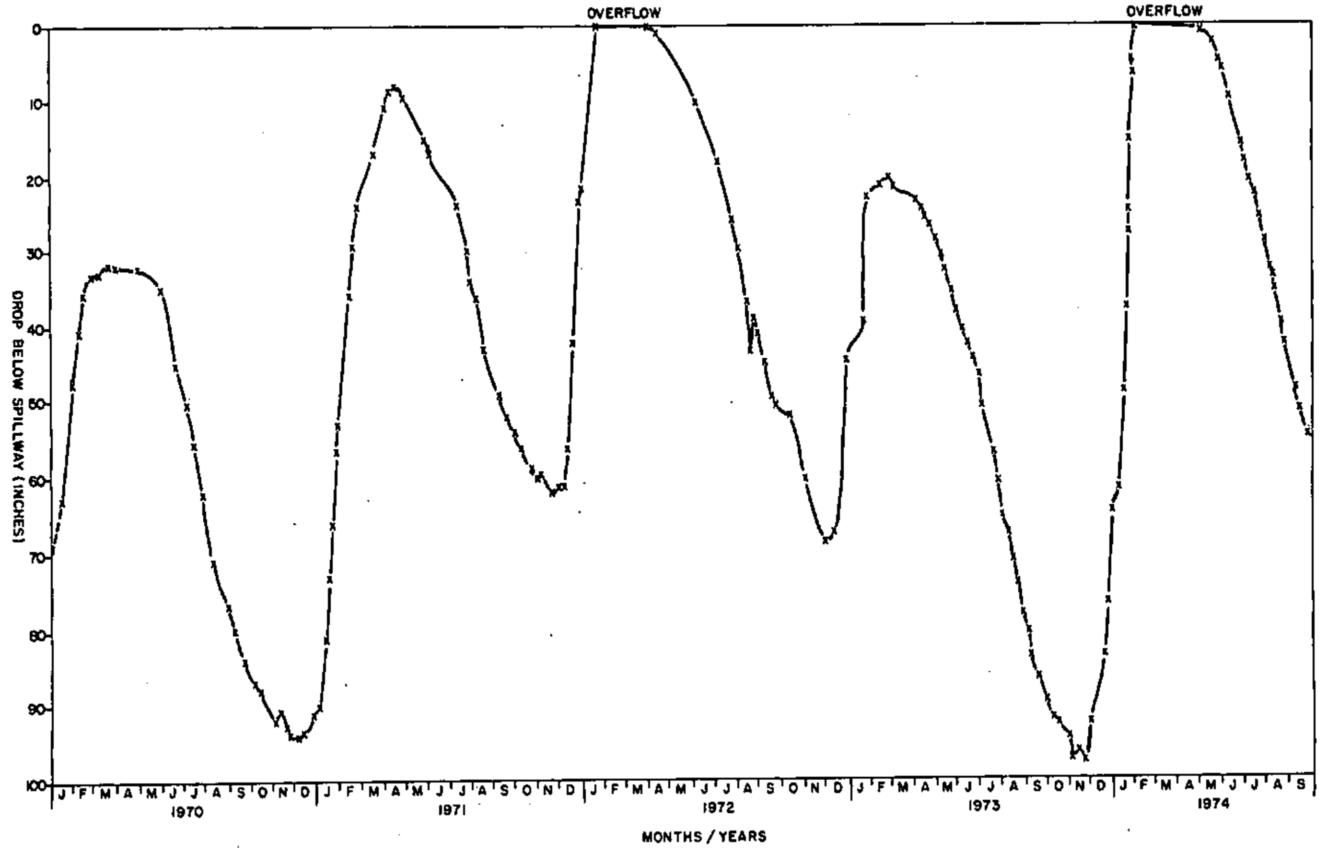


Figure 14. WATER LEVEL FLUCTUATION BEHIND TROUT LAKE DAM.

seepage, and evaporation is approximately equal to recharge from rainfall. As a result, the reservoir has been full only 4 months (February-March 1972, Feb-March 1974) in the 60 months between January 1970 and 1975. Rainfall in the two years in which water did spill from the lake was 1.2-1.3 times greater than the mean annual precipitation (Figure 14).

TABLE 7: Trout Lake Data

Watershed Size: 1.32 square miles
Surface Area: 60± acres
Storage Capacity: 1440± acre-feet
Average Annual Precipitation 1941-1970: 29± inches
Estimated Water Holding Capacity of Soil: 6.00 inches

Annual Consumption by Friday Harbor Water Users:	540 acre-feet
Annual Loss to Evaporation:	100 acre-feet
Annual Loss to Surface Seepage:	20 acre-feet
Annual Total Loss	660 acre-feet

Annual Precipitation:	29 inches
Annual Evapotranspiration:	19.4 inches
Annual Surplus (runoff)	9.6 inches or 676 acre-feet

Water Balance:	676 input
	-660 outflow
	16 acre-feet

Example of Importance of Drought Years:

	Precipitation (inches)	*Runoff (inches)*	
1928	20.63	4.36	or 307 acre-feet
1929	15.08	1.57	or 111 acre-feet
1930	20.94	1.54	or 108 acre-feet
			526 acre-feet

Total input for 3 years:	526 acre-feet
Total outflow (water use, evapotranspiration, seepage)	-1980 acre-feet
	-1454 acre-feet (slightly more than the total capacity of Trout Lake)

The years 1928-30 make up the driest three-year sequence recorded at the Olga 2SE Station. Table 7 shows a calculation of runoff in those years, versus potential demand of the 1970's. This comparison demonstrates how inadequate the Trout Lake supply would be during very dry years for the over 800 people it presently (1975) serves. Since the five years preceding 1928 were dry, storage in Trout Lake was probably significantly below capacity. The deficit of 353 acre-feet in 1928 could have been supplied by residual carryover or storage in the lake, but probably by the end of 1929 and in 1930 Trout Lake would not have been able to supply the needs of a population of 800+ people.

Topography in the Trout Lake watershed is such that downstream relocation of the dam would only slightly increase the storage capacity and total water yield in this watershed. Raising the existing dam would be another way to increase storage and thus increase reservoir capacity to supply water in dry years. But, in most years, water does not spill over the present dam and, therefore this would not increase the total yield from the watershed.

Briggs Pond

Briggs Pond is a privately owned reservoir which supplies domestic water for Roche Harbor. Estimated annual consumption of water by the highly fluctuating population of this resort community is about 80 acre-feet per year. About 50 acre-feet per year is lost from the pond by evaporation. Based on streamflow measurements below this impoundment, it appears that there is little seepage through the dam. The watershed above Briggs Pond is small (less than 0.65 square mile) and, in drought years in which runoff is less than 2 inches (about a 3% chance of occurring any year), recharge would be much less than the amount consumed by domestic use and evaporation (less than 70 acre-feet). Fortunately, because storage capacity is about twice the annual water loss, Briggs Pond should be a reliable water supply in most dry years.

The storage capacity of Briggs Pond could be about doubled by raising the height of its dam, but this would involve the damming of another channel to avoid discharge into another watershed.

Lakedale Lakes

Lakedale Lakes are artificial impoundments created recently in conjunction with a recreational campsite development. Only minor use is made of the lake for domestic water by the owners and visiting campers. If annual evaporation from the lakes (90 acre-feet) is subtracted from estimated contributing annual runoff (250 acre-feet), estimated average annual recharge amounts to about 160 acre-feet. Assuming adequate water quality, Lakedale Lakes could supply, as an average, over 100 acre-feet of water per year. In a drought year, such as 1973, runoff from the 0.42 square-mile watershed above Lakedale Lakes would equal about 140 acre-feet or 50 acre-feet more than evaporation losses from these lakes.

Impoundments could be developed on a few small drainages for irrigation and perhaps domestic supplies; however, there are no additional large potential reservoir sites on San Juan Island.

LOPEZ ISLAND

As Table 8 indicates, Hummel Lake is the only significantly large water body on Lopez Island. Because of poor water quality, it has not been used for domestic water supply. To date, only minor use has been made of this source for irrigation and stock water. Hummel Lake could accommodate some additional use although summer storage in an average year may drop to less than 150 acre-feet.

Henderson Lake is used for domestic supply by Camp Norwester during the summer months.

Approximately 70 other ponds on Lopez Island are used for irrigation and stock water. In the largest watershed on the island (L-1), there are 11 such ponds. Information, obtained by interviews, indicated that most impoundments were quite satisfactory for irrigation and stock water use, during dry years, and despite heavy algal blooms.

TABLE 8: Major Surface Water Bodies on Lopez Island

Water Body	*Estimated Surface Area (acres)*	*Estimated Maximum Storage Capacity (acre-feet)*	*Estimated Average Annual Recharge From Precipitation (acre-feet)*	*Area of Watershed (square miles)*
Hummel Lake	36	272	138	.72
Henderson Lake	8	40	8	.05
Goodrow Lake	4	52	780 (upstream diversions not included)	4.1

BLAKELY AND OTHER ISLANDS

As shown in Table 9, two large lakes on privately owned Blakely Island have a combined storage capacity of approximately 12,500 acre-feet. Horseshoe Lake drains into Spencer Lake, which in turn is used to generate hydroelectric power.

TABLE 9. Blakely and Other Islands–Major Surface Water Bodies

Water Body	*Estimated Surface Area (acres)*	*Estimated Maximum Storage Capacity (acre-feet)*	*Estimated Average Annual Recharge From Precipitation (acre-feet)*	*Watershed Area Above Reservoir (square miles)*
Horseshoe Lake	140	7,300	430	0.85
Spencer Lake (dam)	130	5,200	950	1.78

*Horseshoe Lake flows into Spencer Lake.

On the smaller islands, including Shaw and Decatur, ponded surface waters are used for irrigation and stock water, but generally not for domestic water. Most of these islands are not of sufficient size to capture and store large quantities of runoff.

ESTIMATION OF WATER SUPPLY

From the figures and tables supplied in this text, it is possible to estimate potential water supply from any watershed for mean and drought year conditions. Average annual runoff and drought year runoff for gaged watersheds are listed in Table 10. Average annual runoff for ungaged watersheds can be estimated in the following ways. (1) Use Figure 12 to estimate mean annual runoff, convert the value to feet and multiply the runoff (feet) times the area (acres) of the watershed of interest. (2) Use Figure 1 or Figure 6 to estimate annual precipitation in the watershed and Figure 11 to approximate the runoff from this precipitation. Then multiply the runoff (in feet) times the area (acres) of the watershed of interest. (3) Use Figure 13 to estimate runoff (in feet) and multiply this value and the area (acres) of the watershed.

TABLE 10. Estimated Annual Average and Drought Year Runoff for Watersheds in the San Juan Islands

Basin Plate I	*Precipitation (inches)*	*Runoff (inches)*	*Avg. Year (acre-feet)*	*Drought Year (acre-ft., Max.)*
L-1	21	3.6	345	120
L-2	19	2.1	226	50
O-2	29	9.6	461	70
O-3A	29	9.6	51	70
O-4	28	8.8	230	30
O-5	33	7.2	630	50
O-6	26	12.7	1,097	220
O-7	30	10.3	2,769	430
O-8	28	8.8	1,258	140
O-9	32	11.9	590	110
O-11	25	6.5	447	40
O-12	35	14.4	2,435	530
O-13	25	6.5	482	40
O-14	32	11.9	1,333	170
O-15	39	17.7	614	160
OR-1	39	17.7	359	100
OR-2	36	15.2	949	200
OK-1	35*	15	250	50
OK-2	31*	11.5	74	15
OK-3	34*	13.5	340	50
SJ-1	30	10.3	467	120
SJ-4	23	5	469	50
SJ-5	26	7.2	92	10
SJ-6	26	7.2	288	20
SJ-9	31	11.1	2,267	400
SJ-10	32	11.9	2,190	400
SJ-11A	23	5	117	10
SJ-12	23	5	3,707	400
SJ-13	22	4.4	148	20
SJ-14	29	9.6	778	110

*From precipitation within watershed. At OK-3, combined estimated runoff including significant ground-water contribution from outside the watershed, is about 530 acre-feet.

Drought year runoff can be estimated by two methods: (1) Figure 9 shows the approximate runoff for 1929, the driest year on record at the Olga weather station (0.4% chance of occurring any year). Multiplication of runoff estimated from this figure, and the area (acres) of the watershed will give an approximation of extreme drought water supply in acre-feet. (2) The precipitation of a specific probability of occurrence at the Olga 2SE weather station can be found on Figure 5. Runoff from this precipitation can be estimated from Figure 11, and this times the watershed area will approximate the water supply for the specified frequency of rainfall. Drought rainfall for other parts of the San Juan Islands can be estimated by using Figure 1 to determine average annual rainfall, and then multiplying this value times a proportion defined by Figure 5 for the Olga weather station, to get less frequent rainfall. For example, at Upright Head, on northern Lopez Island, it rains about 26 inches per year (Figure 1). If the drought rainfall at Upright Head that has a 10% chance of occurring in any year is desired, Figure 5 is used. The 10% probability rainfall of 22.7 inches is divided by the average annual rainfall, 29.7 inches for 1945-1973, to obtain the factor 0.76. Average rainfall at Upright Head (26.0 inches) is then multiplied by 0.76 to get 19.87 inches of precipitation. At Upright Head, then, there is a 10% chance that, in any year, precipitation will be less than 19.9 inches. Runoff from this precipitation can then be estimated from Figure 11.

Although this technique is based on meager data, it successfully predicted the drought year precipitation at other weather stations in northern Puget Sound (Sequim, Port Townsend, Port Angeles, and Anacortes). For areas that receive more rainfall than Olga, drought precipitation is somewhat underestimated by this technique.

CONCLUSIONS

The islands of San Juan County, which experience mild winters and cool summers, receive less precipitation than most of the northern Puget Sound. Average annual precipitation at sea level varies from about 19 inches at southern Lopez to about 30 inches at northern Orcas and Waldron Islands. Precipitation also increases with higher elevation resulting in a maximum average annual precipitation of about 45 inches in the Mt. Constitution area. Besides varying with latitude and elevation, average annual precipitation has varied significantly through time. Since 1890, mean precipitation for successive 20 year intervals has ranged from 26 to 31 inches at the Olga weather station of Orcas Island. Currently both annual precipitation and the probability of experiencing severe droughts appear to be increasing; yet it is not possible to predict whether these trends will continue.

A Department of Ecology program of measuring stream flow in 26 creeks once a month, and 2 creeks once daily, from February through December 1974, supplied the basic data needed for estimations of surface water yields from the watersheds on the islands, and made possible a more detailed map of the precipitation distribution. About two-thirds of the precipitation returns to the atmosphere by evapotranspiration. The remaining one-third runs off in small creeks, total runoff varying across the islands proportionately with precipitation. Thus the least amount of annual runoff is discharged from creeks on southern Lopez Island (about 3 inches) and the most runoff is discharged from creeks in the Mt. Constitution area of Orcas Island (about 27 inches).

Runoff is highly seasonal in the San Juan Islands. Typically, most creeks are dry except for rare storm flow, between late April or May and November or December. As a result, discharge in creeks in the San Juan Islands must be impounded to create the storage necessary for a continuous water supply.

Mean annual runoff and drought year runoff from any watershed in the San Juan Islands can be estimated from maps and graphs supplied in this bulletin. Although the data are approximate, it is felt the methods give reasonable results.

Surface water supplies much of the domestic water used on San Juan and Orcas Islands. Trout Lake, as the source of water for the Town of Friday Harbor, is the single most important water supply in San Juan County. Yet because consumption of water from this reservoir in an average year probably exceeds recharge from precipitation in its watershed, maximum use of this water resource has already been achieved and possibly exceeded. If a succession of drought years were to occur, Trout Lake would probably serve inadequately as a water supply.

The only other reservoir used for community water supply on San Juan Island is Briggs Pond, which supplies water for Roche Harbor. Present rate of water consumption from the reservoir is less than the recharge by precipitation, and water in storage in this small reservoir should be enough to supply water in drought years. As a result of topographic limitations no other potential community reservoir sites are apparent.

Numerous ponds, lakes, and springs are used for domestic water on Orcas Island. The Summit Lake-Mountain Lake- Cascade Lake system controls an abundant water supply. At present rate of water use, there may be as much as 4,000 acre-feet per year excess runoff, and as much as 1,100 acre-feet of runoff in a drought year. Another large but unused water supply is Keys Springs, from which perhaps as much as 530 acre-feet per year of water is discharged, with a sizeable proportion occurring during the summer months.

The gentle relief and low precipitation on Lopez Island eliminate the possibility of surface water acting as an important community resource. However, for many people, small ponds have satisfactorily met irrigation and stock water needs.

The Horseshoe Lake - Spencer Lake watershed on Blakely Island possibly experiences about 1,000 acre-feet of runoff in an average year, most of which is not used by the island's population. Surface water supply is probably not significant on the rest of the smaller islands.

RECOMMENDATIONS

Four recommendations are suggested as a result of this investigation. First, the limits of the Trout Lake reservoir should be recognized, and other water resources developed for use in drought years. Possible alternative sources include: Lakedale Lakes, Sportsman Lake, and ground water. Second, runoff through the Summit Lake, Mountain Lake, and Cascade Lake system could be quantified much more accurately. Of critical importance is quantification of the actual precipitation which occurs in these watersheds and determination of that fraction of the runoff which is diverted from Cascade Creek into Cascade Lake. The further quantification of this system would allow for a realistic distribution of surface water rights and a maximizing use of this valuable water resource. If such a program of quantification and planning occurs, the diagram showing the possible climatic trends in precipitation variation should be considered.

A third recommendation is to explore the possibility of capturing the substantial runoff at Keys Springs. The primary problems are how and where to store the water. Lastly, it is suggested that the possibility of improving the water quality of Hummel Lake on Lopez Island be considered, such that, if ground water resources proved to be inadquate in the future, it may serve as a drinking water supply source.

References

1. Gladwell, J. S., 1969, Runoff generation in Western Washington, as a function of precipitation and watershed characteristics, Bull. 319, WSU, College of Eng. Division, Pullman, Washington.
2. Hopper Charlott, J., 1969, A survey of the air pollution climate of the state of Washington, Washington Dept. of Health, Office of Air Quality Control, State of Washington.
3. Phillips, Earl, 1966, Washington climate for these counties, Clallam, Jefferson, Island, San Juan, Skagit, Snohomish, Whatcom. Cooperative Extension Service, College of Agriculture, WSU.EM.2626.
4. Riggs, H. C., 1968, Some statistical tools in hydrology; USGS Techniques of Water Resource Investigations Book 4 Chapter A1, 39 p.
5. Schermerhorn, V. P., 1967, Relations between topography and annual precipitation in Western Oregon and Washington, Water Res., Vol. 3, No. 3, Third Quarter 1967, pp. 707-711.
6. Terwartha, G. T., 1968, An introduction to climate, McGraw-Hill Book Co., New York, New York.
7. Thorthwaite, C. W. and J. R. Mather, 1957, Instructions and tables for computing potential evapotranspiration and the water balance, Drexel Institute of Technology Laboratory of Climatology, Centerton, New Jersey.
8. Wolcott, E. E., 1965, Lakes of Washington, Water Supply Bull. 14, Dept. of Ecology, Olympia, Washington.
9. National Climatic Center, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970, for the state of Washington, Climatology of the U.S. No. 81, Asheville, N.C.
10. Chow V. E., 1964, Handbook of applied hydrology, McGraw-Hill Book Company, New York.
11. Dunne, Tom, 1970, Runoff production in a humid area, U.S. Dept. of Agriculture, Agri. Res. Service ARS 41-60, 18 p.

APPENDIX A

Individual Stream Basin Descriptions

Orcas Island

O-2: Headwaters of this 0.9 square mile watershed drain the east flank of Orcas Knob (1208 feet) and the west flank of the Turtleback Range (highest elevation 1350 feet). The 1957 U.S.G.S. edition of the Orcas Island quadrangle map incorrectly depicts the direction of this stream drainage as due south into Massacre Bay. Instead the channel veers west across the southern base of Orcas Knob before it continues south into Massacre Bay (see Plate 3). Three large bogs, which have a surface area totaling about 10 acres, lie in the lower region of this watershed. Analysis of the results of the streamflow measurements suggest that mean annual runoff in this watershed is about 9.6 inches or 461 acre-feet.

O-3A: The small stream draining this area courses southerly to Massacre Bay. Of the 28 gaged streams in the San Juan Islands, this stream drains the smallest area: 0.10 square mile. When flowing, a waterfall exists near the road along Massacre Bay. Runoff in this basin is mainly generated on the southern flank of the Turtleback Range. In less than 0.5 mile the channel drops 500 feet to Massacre Bay. This watershed, underlain mostly by a thin soil mantle on bedrock, has very little storage potential. Streamflow is derived from seasonal surface runoff and is controlled by the topography and rock fracture pattern of the area. Average annual runoff is estimated to be 9.6 inches or about 51 acre-feet.

O-4: A small stream in this area drains the east flank of the Turtleback Range (1500+ feet) and the west flank of Ship Peak (950+ feet). Its channel courses southerly into two small ponds created by dams, and then crosses under the road and terminates in Massacre Bay. There are three small reservoirs on this 0.49 square mile watershed. These small ponds have a combined surface area totaling about 1 acre, and they serve to maintain a low flow in the stream into the month of June. Annual runoff averages 8.8 inches or 230 acre-feet.

O-5: Two main tributaries, one draining the north side of the Turtleback Range (1500 feet) and the other draining the southwest side of Lookout Mountain (690 feet), meet about ¼ mile above the gaging station to form a main stem stream which flows northwesterly to West Beach and President Channel. Of four small reservoirs totaling less than 1.7 acres in surface area in this 1.62 square mile watershed only one is on a major tributary. Sustained low flow results from springs emanating from sand and gravel deposits at the base of Lookout Mountain. Estimated average annual runoff is 12.7 inches or 1097 acre-feet.

O-6: Discharge from this low lying 1.64 square mile watershed is well regulated by two dams and a marsh, all situated on main tributaries. Water from the 9 acre Fowler Reservoir is used for irrigation. Some water released from this reservoir contributes to low flows. Because of the lower mean elevation of this watershed, it generally produces less annual discharge than most of the other gaged creeks on Orcas Island. On the average, annual runoff is about 7.2 inches or 630 acre-feet.

O-7: Discharging into White Beach Bay at West Sound, this stream receives runoff from the second largest watershed (5.04 square miles) in the San Juan Islands. There are five impoundments, totaling 6 acres in surface area, on the main channel. Estimated average annual runoff of 10.3 inches or 2769 acre-feet is significantly greater than that produced above site O-6, directly to the north, because of the higher precipitation captured by tributaries on the east side of Turtleback Range (1500 feet) and the northwest side of Mt. Woodlard (1200 feet).

O-8: The basin drains a 2.68 square mile area southwest of Mt. Woodlard and discharges into West Sound near Orcas. There is considerable natural storage in the marshes that occupy the gently sloping northern side of Mt. Woodlard in this watershed. Four marshes and three small impoundments totaling about 20 acres in surface area are in the watershed. Average annual runoff is estimated to be 8.8 inches or 1258 acre-feet.

O-9: This measurement site was located at the outlet of Killebrew Lake, where the stream crosses under the main road and flows into Grindstone Harbor. Killebrew Lake receives drainage from the southwest side of Diamond Hill (1002 feet) and the southern extent of the Mt. Woodlard area. During the wet season, Killebrew Lake expands northward and eastward causing discharge to be distributed over a longer time period. Estimated average annual runoff is 11.9 inches or 590 acre-feet.

O-11: Drainage from the northwest side of Mt. Constitution flows through this watershed down a narrow valley in a steeply sloping channel. Although the mean elevation of the watershed is 1100 feet, runoff is only about 6.5 inches or 447 acre-feet per year. This may be a result of a slight rain shadow effect by Mt. Constitution, or this may be a somewhat low estimate of actual discharge. Low flow is sustained by springs through the summer.

O-12 (Cascade Creek): Discharge in Cascade Creek is controlled by the outflow from the small dam at the south end of the 198-acre Mountain Lake. Outflow is regulated by a 5 inch pipe at the base of the dam, by the number of wooden planks set in the spillway, and by seepage. The pipe discharge dominates creek flow at lower stands of the lake. Mountain Lake is surrounded by Mt. Constitution (2409 feet) and Mt. Pickett (1765 feet). There is about 14.4 inches of runoff (2435 acre-feet per year). On Mt. Constitution, Summit Lake (10 acres) drains both into Mountain Lake and across the road into the bogs along Hidden Ridge, because of the height of the planks in the spillway. By lowering the planks about 5 inches, outflow would only occur through the natural channel to Mountain Lake.

Diversion by Doe Bay water users takes place above the measurement site; below the site most of the flow of Cascade Creek is diverted by a canal into Cascade Lake. The 1957 U.S.G.S. Orcas Island quadrangle which shows Cascade Lake and Mountain Lake draining into a main creek which discharges at Olga is no longer correct. Cascade Lake now discharges through a pipe above Rosario creating electrical energy in the water's fall to East Sound.

O-13: This stream receives runoff from the lower, more gently sloping southern extent of the Mt. Constitution-Mt. Pickett upland area. The main channel extends along the base of the slope, collecting runoff and discharging it into East Sound below Buck Bay. Three small bogs and two impoundments, which have a total surface area of less than 4 acres, moderate some of the flow in the 1.39 square mile watershed. One of the dams is directly upstream from the point of measurement. The best estimate of the mean annual runoff is 6.5 inches or 482 acre-feet.

O-14: The 2.10 square mile watershed is similar in form to O-13. Runoff from the central-southeast Mt. Pickett (1765 feet) upland area flows into a channel in a wide valley extending along the base of the steep hillside. The creek discharges into Doe Bay below the measuring site. Two small dams impounding water having a surface area totaling less than 0.5 acre have been built in the watershed. Low flow in the summer is sustained by springs. Estimated average annual runoff is 11.9 inches or 1,333 acre-feet.

O-15: This 0.65 square mile watershed extends in a narrow band up the side of Mt. Pickett. Runoff from the steep hillside flows into a 19 acre reservoir lying across the main channel at the base of the hill. Outflow from this recently constructed dam flows south into the main channel and east into Rosario Strait above Sea Acre. A small pond (surface area of about one acre) stores water for a community just above the stream outlet. Estimated average annual runoff is 17.7 inches or 614 acre-feet per year.

OR-1: Flaherty's Lake receives drainage from Rosario Hill (866 feet) and a lower southwestern ridge of Mt. Constitution. Discharge at the measurement site, which is located where the creek crosses below the access road to Rosario, is regulated by outflow from the bog (2.5 surface acres) in the center of the 0.38 square mile watershed. Streamflow is regulated by natural storage fluctuation of the bog, and as a result total runoff based on a few measurements is difficult to predict. Average annual runoff is about 18 inches.

OR-2 (Cold Creek): Most of the swampy flat area in the Mt. Constitution uplands drains into the steep, narrow, rocky channel of Cold Creek, and discharges near Moran State Park headquarters into Cascade Lake. The actual channel pattern as shown in Plate 3 is significantly different than depicted on the 1959 edition of the U.S.G.S. Orcas Island quadrangle map. Summer low flow is a result of ground water discharges through numerous springs. Estimated average annual runoff for this 1.1 square mile watershed is 15.2 inches or 949 acre-feet.

OK-1: This stream receives runoff from the very steep western flank of the Mt. Constitution highland and discharges into a pond which lies near the county road. Much of the runoff in this 0.31 square mile watershed emanates from numerous springs near the base of the hill. Discharge from the springs have formed several small channels which coalesce into a single, well defined channel. Flow in this channel discharges into a pond (three acres in surface area). These springs sustain a substantial flow during the summer months. Estimated average annual runoff is 15 inches or 250 acre-feet.

OK-2: This watershed, located adjacent to OK-1, drains a more gently sloping flank of the Mt. Constitution highland. Runoff flows in a well defined channel into a pond which is 1.5 acres in surface area. Discharge from this pond flows through an artificial channel into the pond by the county road (OK-1). The runoff from this 0.12 square mile watershed is 11.5 inches or 74 acre-feet in an average year.

OK-3: The combined runoff from the OK-1 and OK-2 watersheds, which discharges from the 3 acre pond, flows under the road and into East Sound. Estimated combined average annual runoff is about 530 acre-feet from the 0.42 square mile watershed.

Lopez Island

L-1: Most of the 4.4 square mile watershed consists of a wide agricultural valley with gentle slopes and a poorly defined main channel. The highest elevation in the watershed is Lopez Hill (535 feet). Runoff is regulated by eleven small dams. Low flow in late spring and early summer is produced by seepage from these dams. The channel terminates just below the measurement site in a large seasonal bog which drains to the west into Davis Bay. During the winter this bog can be over 10 feet deep and in the summer it contains little or no water. Average annual runoff is estimated to be 3.6 inches or 345 acre-feet. This is higher than for L-2 and is probably a result of increased precipitation on Lopez Hill.

L-2: This watershed, consisting of a wide, flat valley and poorly defined drainage channels, is very similar to L-1. Three small ponds created by dams, and totaling less than 0.5 acre in surface area are on the main channel upstream from the gaging station. Over 10% of the watershed is underlain by poorly drained organic soils. Low flow results from springs emanating from a sand deposit immediately upstream from the measurement site. The average annual runoff of 2.1 inches is the lowest of all the gaged streams.

San Juan Island

SJ-1: Most of the 0.85 square-mile watershed drains into the 29-acre Briggs Pond from the east side of Young Hill (650 feet) and the west side of the Cody Mountain upland area. The broad, flat valley in which Briggs Pond lies allows the pond to increase in size and storage until outflow occurs through the dug channel spillway of the earthfill dam at the northwest edge of the pond. A diversion pipe at the dam supplies water to Roche Harbor. Low flow during the summer is the result of seepage from the dam. As with other watersheds in which discharge is completely regulated by dam(s) (OR-1, SJ-10, SJ-12, SJ-14, O-12), it is difficult on the basis of present data to make a good estimate of the average annual runoff. A best approximation is about 10.3 inches or 467 acre-feet per year.

SJ-4: The headwaters of this 1.76 square mile watershed lies in an arcuate shaped, steep sloped hillside ranging in elevation from about 470 to 725 feet. Runoff flows through a broad, grass covered, poorly drained valley, and then through a narrow forested valley. The stream crosses the road at the measurement site and discharges into Andrews Bay. In the watershed there are two pits, one bog modified by damming and three dams which are all on side drainages. The dams are located in the highest part of the watershed near the drainage divide. Estimated average annual runoff is 5 inches or 469 acre feet.

SJ-5: This stream flows through a narrow valley along the base of the northwest edge of the Mt. Dallas upland area and receives drainage from about 0.24 square mile of steep, forested hillslope. Estimated average annual runoff into Smallpox Bay from this watershed is 7.2 inches and 92 acre feet.

SJ-6: Runoff in this watershed from the steep west flank of Mt. Dallas (1240+ feet) flows southward and discharges into Deadman Bay. The upper reaches of the channel are gently sloping and swampy. Several springs emerging from fractures in the bedrock discharge into the swamps and sustain a low flow during part of the summer. Estimated average annual runoff for the 0.75 square mile watershed is 7.2 inches or 288 acre-feet.

SJ-9: Discharge at the measurement site is regulated by outflow from the 66-acre Sportsman Lake. This lake, which is the largest on San Juan Island, receives runoff from a broad, moderately sloping upland region on the northeast side of Cody Mountain. During the wet season Sportsman Lake expands into a wide, flat valley where runoff from precipitation is stored and discharged over a longer time period. Estimated average annual runoff is about 11.1 inches or 2267 acre-feet.

SJ-10: Most of the watershed (Beaverton Valley) consists of a broad, flat valley bordered by moderately sloping, low lying hills. Runoff flows through the valley and discharges into Friday Harbor. Average annual runoff is about 11.9 inches or 2190 acre-feet per year.

SJ-11A: Runoff from the grass-covered San Juan Island golf course drains into three small reservoirs on the main channel which total less than 2.0 surface acres. The largest reservoir in the watershed (1.5 acres), located east of Cattle Point Road, receives drainage from the northwest side of a small hill (167 feet). It discharges along a separate artificial channel along the forested margin of the golf course, and connects with the main channel just above the gravel road but below the measuring site. Flow in the main channel discharges into the bay at Merrifield Cove. Estimated average annual runoff is 5 inches or 117 acre-feet per year.

SJ-12: San Juan Valley Creek has the largest watershed (13.9 square miles) in the San Juan Islands and receives runoff from one-fourth of the island of San Juan. There are about 40 reservoirs, bogs and dug pits in this watershed having a total surface area of 160 acres. Headwaters of the west fork are in the steep mountainous region of Mt. Dallas and Cody Mountain.

The eastern half of the watershed consists of low-lying mountains and grass-covered valleys. All of the runoff from the high west side of this watershed is regulated by Trout and Zylstra Lakes. Outflow from Zylstra Lake and seepage from irrigation in San Juan Valley regulate the flow measured at the measuring site and cause irregular fluctuations in discharge during low flow in the summer. Multiple diversions in this watershed make the estimation less reliable, but a reasonable approximation of average annual runoff is 5 inches or 3707 acre-feet.

SJ-13: This stream discharge measurement site is located above the reservoir at Mulno Cove. Runoff into the reservoir flows from the moderately steep hills (maximum height 331 feet) just east of False Bay. Estimated average annual runoff for the .63 square mile area is 4.4 inches and 148 acre-feet.

SJ-14: Runoff from the southeastern edge of Mt. Dallas drains across the arcuate shaped, wide, gently sloping valley into a steep, narrow valley and into False Bay. Discharge at the measurement site is regulated by fluctuations in storage in a small reservoir just upstream from the station. Low flow is sustained by seepage from the dam. Estimated average annual runoff from this 1.52 square mile watershed is 9.6 inches or 778 acre-feet per year.

APPENDIX B

Table of Ponded Surface Water

The following is a tabulation of surface water bodies compiled from 1969 aerial photographs (1″ = 1000′) and field examination. "Dug pits" are typically small, not located in a stream channel, and are used for stock water and irrigation. Some bogs have been modified by excavation and dam construction. Those recognized from aerial photographs were counted as "impounded bogs". Most on-stream dams are of earthfill construction. Impounded water is used generally for domestic supply, fish propagation, stock watering, irrigation and recreation. Most bogs are shallow, vary greatly in seasonal storage, and are not used as a water supply.

Orcas Island

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	Drainage
T36N	R1W	3D	Bog	1,000	1.4	O-13
		4A	Box	920	.61	O-13
		4Q	Bog	420	2.2	O-13
		5E	Bog	820	.25	
		9B	Bog	320	.08	O-13
		9K	Bog	30	.42	O-13
		9P	Reservoir	2	.26	
		9R	Turek Reservoir	70	7	
		10D	Dug Pit	420	.25	
		15F	Dug Pit	40	.1	
		15M	Bog	120	.09	
		16A	Bog	140	.08	
T36N	R2W	1C	Dug Pit	70	.15	
		1K	Bog	160	.15	
		1L	Dug Pit	180	.05	
		1N/P	Ayer Reservoir	350	10.3	
		3D	Reservoir	170	4.0	O-7
		3E	Reservoir	150	.66	O-7
		3N	Bog	150	.06	O-7
		3P	Reservoir	170	.09	O-7
		4B/G	Reservoir	110	1.3	O-7
		4M	Dug Pit	270	1.0	O-7
		5G/F	Reservoir	50	.25	O-4
		5G	Reservoir	50	.14	O-4
		5G	Reservoir	40	.61	O-4
		6D	Bog	150	8.3	
		6E	Reservoir	150	.84	
		7B	Dug Pit	60	.16	
		7E	Reservoir	100	.22	
		7J	Reservoir	20	.17	
		9B	Quarry Pit	50	.25	
		9Q	Reservoir	160	.14	
		10D	Bog	150	.22	
		10J,H,G	Bog	390	2.5	O-8
		12H	Reservoir	60	4	
		12L/P	Lake Martins (Reservoir)	490	34	
		14D	Bog	370	12	O-8
		14J/R	Killebrew Lake (Bog)	300	13.2	O-9
		15F	Bog	270	.8	
		15G	Bog	270	4.5	O-8
		15H	Reservoir	320	1.8	O-8
		17D	Bog	140	.26	
		17M	Dug Pit	90	1	
		18C	Dug Pit	90	.11	
		22C	Reservoir	70	.52	
		22C	Reservoir	30	.24	
		23B	Reservoir	70	.14	
		23C	Bog	140	.45	
		23D	Dug Pit	140	.45	O-8
		23E	Bog	150	.48	O-8
		23G	Reservoir	100	.17	
		23H	Reservoir	40	.29	
		24L	Dug Pit	70	.39	
T36N	R3W	1K	Reservoir	50	1	
		12A	Bog	120	6.7	
		12K	Bog	380	1.4	
		12Q	Bog	340	1.3	
T37N	R1W	7L/P	Dug Pit	70	.17	

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	
		7N	Dug Pit	50	.46	
		7P	Dug Pit	150	.35	
		17L/M	Day Lake (Reservoir)	1,260	12	
		18B	Dug Pit	850	.09	
		18J	Bog	1,300	6	
		19N	Reservoir	70	3	OK-3
		19N	Reservoir	90	1.5	OK-3
		20H	Bog	1,750	.39	O-11
		20J	Bog	2,220	1	OR-2
		20L/M	Dug Pit	1,940	.5	OR-2
		21J/K	Twin Lakes (Bogs)	1,100	8.3	
		26J	Utters Reservoir	410	10	O-15
		27Q	Bog	1,600	1.8	O-14
		28D	Summit Lake (Reservoir)	1,100	10	O-12
		29B	Bog	2,050	.20	OR-2
		29B/G	Bog	2,050	5.0	OR-2
		29H/A	Bogs	2,100	.16	
		29J/H	Bog	2,050	1.4	
		29G	Bog	2,050	.44	
		30/25D	Reservoir	110	.44	
		30/25D	Reservoir	70	.35	
		31C	Flaherty's Lake (Bog)	440	2.5	OR-1
		31P	Cement Ponds	40	.33	
		32P	Cascade Lake (Reservoir)	345	172	
		34M	Mountain Lake	915	198	O-12
		35F	Reservoir	300	.28	O-14
		35G	Reservoir	260	.21	O-14
		36G	Reservoir	100	1	
T37N	R2W	11E	Dug Pit	50	.25	
		11L	Dug Pit	30	1	
		11M/N	Bog	140	1.5	
		11P/Q	Dug Pit	30	.19	
		12Q	Bog	30	.32	
		12Q	Dug Pit	30	1.3	
		13E	Bog	10	.37	
		14C	Dug Pit	160	.33	
		14G	Reservoir	20	.05	
		15P	Dug Pit	370	.43	O-5
		21G	Reservoir	80	.54	O-5
		21J	Dug Pit	200	.55	O-5
		21Q	Reservoir	130	.64	O-5
		22K	Fowler Reservoir	130	9	O-6
		26M	Reservoir	250	1.2	O-6
		27A	Reservoir	180	1.7	O-6
		27J	Bog	240	.41	O-6
		27N	Dug Pit	130	.18	O-7
		27R	Dug Pit	290	.25	O-7
		28G	Bog	330	.1	O-6
		28Q	Dug Pit	500	.39	O-7
		28R	Reservoir	140	4.7	O-7
		28R	Reservoir	140	.61	O-7
		28R	Reservoir	140	.39	O-7
		29R	Bog	1,400	.5	
		31K	Bog	230	3.5	O-2
		31J	Bog	200	2.9	O-2
		31K	Bog	250	4.0	O-2
		31R/J	Reservoir	150	.26	
		32A/H	Bog	1,020	.83	O-7

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	
		33B	Dug Pit	200	.13	O-7
		33F	Bogs	250	.28	O-7
		33F	Dug Pit	300	.5	O-7
		34K	Dug Pit	200	.79	O-7
		34H	Bog	250	.37	O-7
		34L	Dug Pit	190	.11	O-7
		34Q	Bog	180	.18	O-7
		35K	Bog	150	.23	
		35P	Bog	360	1	

San Juan Island

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	Drainage
T34N	R2W	2A	Bog	110	.10	
		2G	Dug Pit	150	.90	
		2G	Bog	150	.25	
		3F	Reservoir	170	1.39	
		3J	Dug Pit	150	.03	
		3K	Dug Pit	80	.04	
		4A	Dug Pit	70	.08	
T35N	R2W	18F	Bog	110	.06	
		18K	Bog	30	5	
		18L	Dug Pit	70	.06	
		18N	Bog	200	3.2	
T35N	R3W	2M	Reservoir	150	2.9	SJ-10
		3E	Dug Pit	170	.5	SJ-10
		3G	Reservoir	190	.5	SJ-10
		3K	Reservoir	150	.42	SJ-10
		3L	Bog	110	.58	SJ-10
		4A	Bog	160	.05	SJ-9
		4B	Bog	150	7.3	SJ-9
		*4G	Bog	150	.26	SJ-9
		4N	Bog	190	2.6	SJ-12
		5C	Dug Pit	320	.72	SJ-9
		5H	Reservoir	210	.60	SJ-9
		5H	Dug Pit	210	.02	SJ-9
		5J	Dug Pit	230	.11	SJ-9
		5K	Reservoir	250	.11	SJ-12
		7D/E	Lawson Lake (Reservoir)	305	12.5	SJ-12
		7H	Reservoir	290	2.9	SJ-12
		7J	Reservoir	280	.12	SJ-12
		8C	Dug Pit	240	.22	SJ-12
		8D	Dug Pit	250	.32	SJ-12
		8G	Reservoir	150	3.1	SJ-12
		8L	Bog	120	1.6	SJ-12
		9A	Reservoir	170	.11	SJ-10
		9M	Reservoir	100	5.0	SJ-12
		10C	Bog	130	.96	SJ-10
		10F	Bog	120	.39	SJ-10
		10M	Bog (Channel)	100	.30	SJ-10
		10L	Dug Pit	100	.06	SJ-10
		11H	Dug Pit	100	.04	SJ-10
		11L	Dug Pit	100	.61	
		11M	Dug Pit	110	.11	
		11Q	Dug Pit	100	.10	
		12C	Sewage Lagoons/ Dug Pits	80	.20	

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	
		13G	Dug Pit	10	.25	
		14E	Reservoir	130	1.5	SJ-12
		14M	Reservoir	90	.45	SJ-12
		14N	Reservoir	120	.81	SJ-12
		14K	Dug Pit	90	.09	
		14R	Reservoir	60	.15	
		15B	Bog	140	.83	SJ-9
		15C	Bog	150	1.5	SJ-12
		15E	Reservoir	120	.10	SJ-12
		15G	Dug Pit	110	.11	SJ-12
		15G	Dug Pit	100	.30	SJ-12
		15P	Dug Pit	100	.02	SJ-12
		16A	Dug Pit	190	.08	SJ-12
		16C	Bog	140	4.6	SJ-12
		16E	Reservoir	150	3.3	SJ-12
		16G	Dug Pit	170	.08	SJ-12
		16M	Reservoir	110	13.2	SJ-12
		16N	Reservoir	80	.46	SJ-12
		18M	Trout Lake (Reservoir)	250	46	SJ-12
		19G	Woods Reservoir	180	18	SJ-12
		20A/B	Zylstra Lake (Reservoir)	35	53	SJ-12
		20G/H	Reservoir	30	3.2	SJ-12
		20E	Reservoir	260	.83	SJ-12
		20E	Reservoir	260	.26	SJ-12
		21D	Reservoir	60	.10	SJ-12
		22K	Dug Pit	90	.04	SJ-12
		22L	Dug Pit	50	.20	SJ-12
		22R	Dug Pit	220	.19	
		23A	Reservoir	20	.10	
		23B	Dug Pit	90	.03	
		23J	Reservoir	10	.18	
		23K	Reservoir	30	.08	
		26G	Reservoir	30	.62	SJ-11A
		26G	Reservoir	45	.17	SJ-11A
		26G	Reservoir	40	.19	SJ-11A
		26J	Dug Pit	50	.10	
		26L	Reservoir	90	1.5	SJ-11A
		26N	Dug Pit	100	.14	SJ-11A
		26Q	Reservoir	25	1.0	SJ-13
		27H	Bog	150	.15	SJ-12
		27K	Dug Pit	110	.11	
		27K/Q	Dug Pit	100	.12	SJ-13
		27Q	Dug Pit	100	1.4	SJ-13
		28C	Reservoir	30	.50	SJ-12
		28N	Bog	135	.77	
		28N	Bog	130	.44	
		28N	Dug Pit	150	.11	
		29D	Dug Pit	170	.34	SJ-14
		29D	Heidenreichs Lake (Reservoir)	150	6	SJ-14
		29F	Reservoir	145	1.4	SJ-14
		29G	Reservoir	260	.45	SJ-14
		29K	Dug Pit	220	.06	SJ-14
		29N	Bog	115	.28	
		30D	Reservoir	285	2.1	SJ-14
		30E	Reservoir	270	1.0	SJ-14
		30C/F	Reservoir	260	7.8	SJ-14
		30J	Dug Pit	155	.99	
		31A	Dug Pit	30	.13	
		33E	Reservoir	30	.99	

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	
		33R	Dug Pit	70	.16	
		34F	Dug Pit	230	.11	
		34H	Reservoir	210	.26	SJ-13
		35A	Dug Pit	35	.57	
		35A	Dug Pit	70	.22	
		35B	Reservoir	40	.30	SJ-13
		35E	Reservoir	140	.48	SJ-13
		35F	Dug Pit	120	.37	
		35M	Bog	190	5.5	SJ-13
		35P	Dug Pit	210	.12	
		36N	Dug Pit	30	.14	
T35N	R4W	1B/C	Bog	75	2.0	
		1C	Bog	65	.5	
		1N	Dug Pit	80	.51	SJ-4
		2D	Reservoir	190	2.6	
		2J	Dug Pit	70	.3	SJ-4
		2L	Dug Pit	85	.27	SJ-4
		12H	Reservoir	420	.89	SJ-4
		12M	Reservoir	460	.25	SJ-4
		12M	Reservoir	450	.28	SJ-4
		12N	Bog	450	1.2	SJ-12
		24B	Bog	790	.5	SJ-12
		24G	Bog	830	1	SJ-14
T36N	R3W	18B	Dug Pit	30	.61	
		18M	Dug Pit	190	.11	
		19H	Dug Pit	50	.36	
		19L	Bog	110	.12	
		19P	Dug Pit	200	.07	
		28E	Reservoir	200	1.0	
		28L	Impounded Bog	300	.32	
		28P	Impounded Bog	210	.37	
		28P	Impounded Bog	210	.28	
		29A	Dug Pit	210	1.0	
		29D	Bog	190	.23	
		30E	Briggs Pond (Reservoir)	220	29.1	SJ-1
		31Q/R	Three Corners Lake (Reservoir)	420	2.8	SJ-9
		32A	Lakedale Lakes (Reservoir)	200	50	
		32Q	Bog	470	.05	SJ-9
		33H	Reservoir	240	1.5	SJ-9
		33J	Reservoir	240	1.4	SJ-9
		33J	Bog	245	.03	SJ-9
		33K	Bog	190	.08	SJ-9
		33N	Egg Lake (Bog)	155	6.6	SJ-9
		33Q	Sportsman Lake (Impounded Bog)	150	66	SJ-9
T 36N	R4W	23H	Quarry Pit	90	.19	
		23K	Quarry Pit	90	.28	
		23L	Bog	5	1.9	
		26L	Bog	5	..50	
		35D	Impounded Bog	45	.51	
		35D	Bog	50	.06	
		35F	Dug Pit	30	.06	
		36E	Bog	15	1.7	
		36M	Bog	20	3.0	
		36N	Bog	20	7.5	
		36P	Bog	60	.05	

Lopez Island

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	Drainage
T34A	R1W	5H	Henderson Lake	30	8.0	
		9P	Dug Pit	75	.02	
		9N	Dug Pit	150	.04	
		7N	Dug Pit	210	.16	
		16B	Dug Pit	90	.05	
		16C	Dug Pit	120	.04	
		16E	Dug Pit	130	.02	
		16L	Dug Pit	170	.04	
		17H	Dug Pit	100	.13	
		17N	Reservoir	150	1.6	
		17N	Bog	150	.02	
		17N	Bog	150	.02	
		19A	Dug Pit	20	.03	
T34N	R2W	1J	Impounded Bog	250	.44	
		1R	Impounded Bog	240	.15	
		1E	Impounded Bog	250	1.6	L-1
		1D	Dugout Bog	310	.05	L-1
		2N	Reservoir	50	.22	L-1
		2L	Reservoir	100	.07	L-1
		2F	Reservoir	120	.44	L-1
		2B	Reservoir	200	.44	L-1
		2B	Reservoir	210	.96	L-1
		2A	Reservoir	220	.37	L-1
		2G	Dug Pit	180	.06	L-1
		3A	Reservoir	150	.07	L-2
		3K	Reservoir	150	.08	L-2
		3N	Dug Pit	90	.03	
		4A	Bog	170	.44	
		10H	Dug Pit	50	.09	
		10G	Reservoir	5	.79	
		11B	Reservoir	90	4.0	L-1
		11D	Dug Pit	50	.03	L-1
		12G	Reservoir	100	.88	L-1
T35N	R2W	1M	Reservoir	5	.26	
		10B	Flathead Lake (Bog)	5	2.5	
		11A	Dug Pit	40	.08	
		11M	Dug Pit	160	.02	
		12L	Reservoir	30	.10	
		12K	Bog	2	4.0	
		14A	Dug Pit	130	.07	
		14F	Bog	120	3	
		23A	Hummel Lake (Bog)	100	36	
		23C	Dug Pit	75	.07	
		23C	Dug Pit	75	.03	
		23D	Reservoir	50	.19	
		23H	Dug Pit	200	.08	
		23R	Dug Pit	220	.06	
		24N	Reservoir	200	1.6	
		26A	Dug Pit	270	.69	
		26B	Impounded Bog	240	.18	L-1
		26G	Dug Pit	260	.06	L-1
		26H	Dug Pit	260	.23	
		26J	Impounded Bog	275	.22	L-1
		26R	Impounded Bog	250	.09	L-1
		26J	Dugout Bog	275	.22	L-1
		26M	Reservoir	210	.02	L-2
		26R	Impounded Bog	250	.09	L-1

Location Township	Range	Section	Name/Type	Approximate Elevation Above Mean Sea Level	Approximate Area (acres)	
		27R	Dug Pit	220	.10	L-2
		28K	Dug Pit	10	.08	
		33J	Dug Pit	170	.005	L-2
		33K	Bog	160	.11	
		33Q	Dug Pit	160	.10	
		34A	Reservoir	190	.29	L-2
		34F	Dug Pit	190	.12	
		34H	Reservoir	170	.19	L-2
		34P	Reservoir	140	.03	L-2
		35A	Impounded Bog	240	.12	L-1
		35J	Dug Pit	260	.04	L-1
		35L	Reservoir	200	.03	L-1
		35M	Dug Pit	170	.03	L-1
		35P	Reservoir	160	.24	L-1
		35R	Dug Pit	320	.06	L-1
		36A	Bog	90	.04	
			Shaw Island			
T35N	R2W	4D	Bog	30	9.6	
T36N	R2W	20Q	Dug Pit	120	.04	
		20R	Dug Pit	30	.08	
		26E	Dug Pit	140	.28	
		26L	Bog	180	1.2	
		27A	Impounded Bog	60	.23	
		27J	Bog	40	.45	
		27N	Impounded Bog	70	.28	
		28D	Bog	130	4.6	
		28J	Reservoir	130	.6	
		29B	Impounded Bog	70	1.2	
		29L	Bog	170	.005	
		29Q	Bog	250	5.1	
		29Q/R	Bog	300	.72	
		29R	Bog	250	1.5	
		33Q	Bog	230	3.0	
		33E	Dug Pit	170	.74	
		33G	Dug Pit	140	.55	
		33P	Bog	30	.6	
		34C	Impounded Bog	30	.41	
		34D	Bog	70	.5	
		34K	Impounded Bog	10	.5	
		34L	Impounded Bog	10	.66	
			Blakely Island			
T35N	R1W	4G	Spencer Lake (Reservoir)	200	64	
T36N	R1W	33N	Horseshoe Lake	350	84	
		34K	Bog	570	5.7	
		34L	Bog	630	1.1	
			Decatur Island			
T35N	R1W	20A	Impounded Bog	30	2.3	
		21Q	Dug Pit	60	.07	
		22G	Bog	10	6	

APPENDIX C

Miscellaneous Streamflow Records

The following is a list of streamflow measurements made by the Department of Ecology personnel in 1974 in San Juan County streams. For convenience, each flow measurement site was assigned a number and a letter indicating the island ("L":Lopez, "O":Orcas, "SJ":San Juan). Drainage areas were determined by use of a planimeter and U.S. Geological Survey topographic maps. Mean elevations were estimated by finding the average elevation between the highest point in a watershed and the discharge measurement station elevation (half of sum of the highest elevation and gage station elevation). Mean elevation can be used as an index to average annual precipitation and, therefore, runoff in a watershed. General remarks about diversions and water rights in each watershed are also included.

Explanation of symbols

t. = trace amount of discharge, unmeasureable flow
n.f. = no flow, but standing water in stream bed
cfs = cubic feet per second, 1 cfs is equivalent to about 450 gallons per minute.

San Juan Island

Station Number: SJ-1

Location: T. 36N., R. 4W., Sec. 32–SW¼SE¼SW¼SE¼. Above culvert in bend of road; 1.3 miles southeast of Roche Harbor.
Drainage Area: 0.85 square mile
Station Elevation: 160 feet
Mean Elevation: 405 feet
Remarks: Briggs Pond, a 29.1 acre reservoir, is ½ mile upstream from station; about 80 acre-feet are diverted each year to Roche Harbor from this private reservoir. Low flow derived from reservoir seepage.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/30	3.20	7/30	0.0003
2/27	0.75	8/26	Dry
3/27	0.69	9/24	Dry
4/24	0.12	10/22	n.f.
6/5	0.02	11/11	0.01
6/25	0.002	12/11	0.01
7/17	0.002		

Station Number: SJ-4

Location: T. 35N., R. 4W., Sec. 2–SW¼SW¼SE¼SW¼. Above culvert under road north of Andrews Bay.
Drainage Area: 1.76 square miles
Station Elevation: 40 feet
Mean Elevation: 383 feet
Remarks: No recorded diversions above station in main channel. In watershed there are two excavated pits, one bog and three small ponds resulting from dam construction. Surface area of these impoundments is less than 4 acres.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	8.78	7/30	t.
2/27	1.33	8/27	Dry
3/27	1.68	9/24	Dry
4/24	0.22	10/22	Dry
6/5	0.15	11/11	0.01
6/25	0.001	12/11	0.01

Results of staff gaging reported on page (Table) of appendix

Station Number: SJ-5

Location: T. 35N., R. 4W., Sec. 11–SW¼SW¼SW¼SE¼. Culvert under road on west side of road, 0.3 miles south of entrance to San Juan County Park.
Drainage Area: 0.2 square miles
Station Elevation: 145 feet
Mean Elevation: 423 feet
Remarks: No recorded diversions.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	0.79	7/30	Dry
2/27	0.21	8/27	Dry
3/27	0.20	9/24	Dry
4/24	0.04	10/22	Dry
6/5	0.02	11/11	Dry
6/25	Dry	12/11	Dry

Station Number: SJ-6

Location: T 35N., R. 4W., Sec. 24–SE¼NE¼SW¼SW¼. Culverts under bend in road, southwest of Mt. Dallas, northeast of Deadman Bay.
Drainage Area: 0.75 square mile
Station Elevation: 60 feet
Mean Elevation: 570 feet
Remarks: Small diversion of spring water from base of Mt. Dallas.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	2.78	7/30	0.003
2/27	0.58	8/27	0.0002
3/27	0.72	9/24	Dry
4/24	0.22	10/22	Dry
6/5	0.07	11/11	0.01
6/25	0.09	12/11	0.04

Station Number: SJ-9

Location: T 36N., R. 3W., Sec. 34–SE¼SW¼SW¼SW¼. Culvert under Roche Harbor Road.
Drainage Area: 3.83 square miles
Station Elevation: 150 feet
Mean Elevation: 522 feet
Remarks: Over 30 acres of ponded surface water in watershed. Discharge moderated by Sportsman

Lake (66 acres). No diversion in 1974. Water rights permit diversion of about 480 acre-feet per year for irrigation.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/30	20.46	7/30	Dry
2/27	4.32	8/27	Dry
3/27	4.03	9/24	Dry
4/24	0.86	10/22	Dry
6/5	0.33	11/11	Dry
6/25	0.001	12/11	0.02

Station Number: SJ-10 (Beaverton Valley Creek)

Location: T. 35N., R. 3W, Sec. 11–NW¼SE¼SE¼NE¼. Culvert under road to University of Washington Oceanographic Laboratories; 0.4 miles from Friday Harbor

Drainage Area: 3.45 square miles

Station Elevation: 50 feet

Mean Elevation: 256 feet

Remarks: Eleven small impoundments having a surface area of about 10 acres are present above measuring site. About 17 acre-feet per year is permitted to be diverted for stock and general use.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/30	17.46	7/30	Dry
2/28	2.89	8/27	Dry
3/27	2.60	9/24	Dry
4/9	3.42	10/22	n.f.
4/24	0.80	11/11	n.f.
6/5	0.12	12/11	n.f.
6/25	n.f.		

Station Number: SJ-11A

Location: T. 35N., R. 3W., Sec. 26–SW¼SW¼SE¼NE¼. Above and below the road at Merrifield Cove; east of San Juan Golf Course.

Drainage Area: 0.44 Square mile

Station Elevation: 20 Feet

Mean Elevation: 135 feet

Remarks: 4 dams on the main channel; Surface area ponding is less than 3 acres. Low flow is because of seepage from golf course pond immediately upstream. Irrigation water rights permit the diversion of about 40 acre-feet per year from a pond at the golf course.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	1.54	7/30	0.002
2/27	0.42	8/27	0.0003
3/27	0.23	9/24	0.001
4/24	0.02	10/22	0.001
6/5	0.01	11/11	0.003
6/26	0.004	12/11	0.002

Station Number: SJ-12 (San Juan Valley Creek)

Location: T. 35N., R. 3W., Sec. 28–NW¼NE¼NE¼SE¼. About 100 feet south of westside road across San Juan Valley.

Drainage Area: 13.9 square miles

Station Elevation: 15 feet

Mean Elevation: 545 feet

Remarks: There are about 40 bodies of water in the watershed, totaling over 160 surface acres. Low flow is controlled by seepage and irrigation diversion from Zylstra Lake. In an average year all of the runoff from 1.32 square miles of the watershed is impounded by Trout Lake from which 600 acre-feet per year are diverted to Friday Harbor. Water rights allow diversion of a total of 890 acre-feet per year for irrigation.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/13	12.92	7/30	n.f.
2/27	11.95	8/27	0.16
3/27	3.27	9/24	0.03
4/24	0.34	10/22	0.12
6/5	0.07	11/11	0.91
6/26	n.f.	12/11	0.42

Station Number: SJ-13

Location: T. 35N., R. 3W., Sec. 35–SW¼NW¼NW¼NE¼. About 0.16 miles east of Cattle Point Road.

Drainage Area: 0.63 square mile

Station Elevation: 75 feet

Mean Elevation: 203 feet

Remarks: 5 ponded water areas above the gaging site, totaling less than 7 acres. About 20 acre-feet per year are used for irrigation according to water rights records.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	2.81	7/30	Dry
2/26	0.41	8/27	Dry
3/27	0.29	9/24	Dry
4/24	0.01	10/22	Dry
6/5	n.f.	11/11	Dry
6/26	n.f.	12/11	Dry

Station Number: SJ-14

Location: T. 35N., R. 3W., Sec. 32–NE¼NE¼SE¼NE¼. At concrete spillway for pond which is just north of West Side Road.

Drainage Area: 1.52 square miles

Station Elevation: 140 feet

Mean Elevation: 558 feet

Remarks: Surface area of pond is 1.4 acres. About 11 acres of impounded water occurs above the measuring site; the largest pond has a surface area of 7.8 acres.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/31	6.33	7/30	Dry
2/27	1.90	8/27	Dry
3/27	0.99	9/27	Dry
4/24	0.15	10/22	Dry
6/5	0.01	11/11	Dry
6/25	Dry	12/11	Dry

Station Number: SJ-14

Location: T. 35N., R. 3W., Sec. 33–NE¼NW¼SW¼NW¼. 500 feet from above station and south of road.
Drainage Area: 1.52 square miles
Station Elevation: 110 feet
Mean Elevation: 535 feet
Remarks: Low flow values are measurements of seepage from upstream pond.

Station Number: SJ-TL

Location: T. 35N., R. 3W., Sec. 18, SE¼NW¼SW¼. At base of Trout Lake Dam.
Drainage Area: 1.32 square miles
Station Elevation: 250 feet
Mean Elevation: 547 feet
Remarks: Seepage at base of dam

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
6/26	0.03	10/22	0.01
7/17	0.03	11/11	0.02
7/30	0.05	12/11	0.03

ORCAS ISLAND

Station Number: O-2

Location: T. 37N., R. 2W., Sec. 31–SE¼SE¼SE¼. North of culvert under road along Massacre Bay.
Drainage Area: 0.90 square mile
Station Elevation: 70 feet
Mean Elevation: 548 feet
Remarks: 3 large bogs in the headwaters (totaling about 10 acres in surface area) moderate discharge. Water rights permit the diversion of 8 acre-feet per year for domestic supply.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	3.73	7/29	Dry
2/26	0.93	8/26	Dry
3/25	0.93	9/23	Dry
4/22	0.31	10/22	t.
6/3	0.12	11/12	0.01
6/24	0.02	12/10	n.f.

Station Number: O-3A

Location: T. 36N., R. 2W., Sec. 5–NE¼NW¼NW¼. Measured east and west of road along Massacre Bay.
Drainage Area: 0.10 square mile
Station Elevation: 70 feet
Mean Elevation: 735 feet
Remarks: No recorded diversions

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	0.48	7/29	Dry
2/26	0.12	8/26	Dry
3/25	0.04	9/23	Dry
4/22	Dry	10/22	Dry
6/3	Dry	11/12	Dry
6/24	Dry	12/10	t.

Station Number: O-4

Location: T. 36N., R. 2W., Sec. 5–SW¼SW¼NE¼. Above and below road along Massacre Road.
Drainage Area: 0.49 square mile
Station Elevation: 40 feet
Mean Elevation: 770 feet
Remarks: Low flow is seepage from pond immediately upstream. There are 3 impoundments on the main channel with a total surface area of about one acre.

Discharge Measurements in 1974

Date	*Amount*	*Date*	*Amount*
1/29	1.51	7/29	Dry
2/26	0.49	8/26	Dry
3/25	0.38	9/23	Dry
4/22	0.08	10/22	Dry
6/3	0.05	11/12	0.004
6/24	0.01	12/10	Dry

Station Number: O-5

Location: T. 37N., R. 2W., Sec. 21–NW¼SW¼NE¼. Below culvert, west of the road, 0.1 miles from West Beach.
Drainage Area: 1.62 square miles
Station Elevation: 40 feet
Mean Elevation: 770 feet
Remarks: There is one dam with a 0.5 acre reservoir on the main channel about 1500 feet upstream from station. Low flow is discharge from springs in headwaters. Diversion of about 40 acre-feet per year is permitted for domestic use and irrigation.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	6.01	7/29	0.02
2/26	2.73	8/27	0.01
3/26	1.59	9/23	0.01
4/22	0.62	10/23	0.02
6/4	0.47	11/12	0.17
6/24	0.05	12/10	0.24

Station Number: O-6

Location: T. 37N., R. 2W., Sec. 22–NE¼NE¼SE¼. south of road above culvert and about 0.2 mile from Judd Cove.

Drainage Area: 1.64 square miles
Station Elevation: 140 feet
Mean Elevation: 420 feet
Remarks: There are two dams and a bog on the main side tributary channel. The impoundments have a surface area totaling 11 acres. The low flows are measurements of seepage and irrigation drainage from Fowler Reservoir, a pond having a surface area of 9 acres and which is about 1000 feet upstream. Water rights allow about 42 acre-feet for irrigation and domestic use.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/1	7.3	7/29	0.04
2/26	3.71	8/26	n.f.
3/26	0.84	9/23	0.06
4/22	0.27	10/23	0.09
6/4	0.09	11/12	0.98
6/24	0.02	12/10	0.48

Station Number: O-7

Location: T. 36N., R. 2W., Sec. 4–SE¼NE¼SW¼. North of road above culvert at bend in road–0.1 mile from West Sound.
Drainage Area: 5.04 square miles
Station Elevation: 15 feet
Mean Elevation: 757 feet
Remarks: There are 5 dams on the two main channels, with the surface area of the impoundments totaling about 6 acres. Water right claims for domestic use, irrigation, fire protection and fish propagation total 340 acre-feet.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	17.01	7/29	t.
2/26	11.29	8/27	n.f.
3/25	3.55	9/23	n.f.
4/22	1.09	10/22	n.f.
6/3	0.27	11/12	n.f.
6/24	0.01	12/10	0.21

Station Number: O-8

Location: T. 36N., R. 2W., Sec. 22–SE¼NE¼NW¼. About 0.5 miles east of Ferry landing, south of road.
Drainage Area: 2.68 square miles
Station Elevation: 50 feet
Mean Elevation: 625 feet
Remarks: No recorded diversions; Ponds in watershed have a total surface area of 8 acres.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/1	8.03	7/27	0.003
2/27	3.07	8/26	t.
3/25	2.25	9/23	t.
4/22	0.62	10/22	0.002
6/3	0.08	11/12	0.03
6/24	0.01	12/10	0.03

Station Number: O-9

Location: T. 36N., R. 2W., Sec. 14–NE¼SE¼SE¼. At outlet of Killebrew Lake, above road.
Drainage Area: 0.93 square mile
Station Elevation: 50 feet
Mean Elevation: 670 feet
Remarks: Discharge measurements are outflow from Killebrew Lake. No known diversions.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/1	3.77	7/27	Dry
2/12	1.21	8/26	Dry
2/27	1.31	9/23	Dry
3/25	1.13	10/22	Dry
4/22	0.26	11/12	Dry
6/3	0.07	12/10	Dry
6/24	n.f.		

Station Number: O-11 (High Discharges)

Location: T. 37N., R. 1W., Sec. 19–SW¼SW¼NW¼. About 0.1 mile east of road and 1.5 miles southeast of East Sound.
Drainage Area: 1.29 square miles
Station Elevation: 150 feet
Mean Elevation: 1100 feet
Remarks: No recorded diversions.

Discharge Measurements in 1974 (cfs)

Date	*Amount*
1/29	6.54
2/26	1.22
3/26	0.77
4/23	0.22

Station Number: O-11 (Low Discharges)

Location: T. 37N., T. 2W., Sec. 24–NE¼NE¼SE¼. West of road just below culvert.
Drainage Area: 1.32 square miles
Station Elevation: 50 feet
Mean Elevation: 1050 feet
Remarks: No recorded diversions

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
6/4	0.53	9/23	0.0004
6/24	0.13	10/23	0.001
7/29	0.054	11/12	0.011
8/27	0.004	12/10	0.228

Station Number: O-12 (Cascade Creek)

Location: T. 37N., R. 1W., Sec. 33–SW¼SW¼SW¼. About 380 feet northwest of road to Olga in Moran State Park.
Drainage Area: 3.17 square miles
Station Elevation: 450 feet
Mean Elevation: 1150 feet
Remarks: Outflow from Mountain Lake by spillover dam and discharge from a 5-inch pipe at base of dam.

Doe Bay water users divert water above the station at dam on Mountain Lake. They have water rights for about 94 acre-feet per year.

Discharge Measurements

Date	*Amount*	*Date*	*Amount*	*Date*	*Amount*
1/28	35.72	6/4	3.18	9/23	0.18
2/12	13.29	6/27	0.92	10/23	0.28
2/26	5.89	7/29	0.55	11/12	0.63
3/26	5.43	8/27	0.40	12/10	0.67
4/23	2.90				

Station Number: O-13 (High Discharge)

Location: T. 36N., R. 1W., Sec. 9—SE¼NE¼SW¼. West of road below culvert, east of Buck Bay. 0.4 miles east of Olga.
Drainage Area: 1.39 square miles
Station Elevation: 40 feet
Mean Elevation: 557 feet
Remarks: Water rights permit diversion of 30 acre-feet per year recorded for irrigation and domestic use. Reservoirs have a total surface area of less than 4 acres.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	5.33	4/23	0.33
2/26	1.72	6/5	0.39
3/26	0.81		

Station Number: O-13 (Low Discharge)

Location: T. 36N., R. 1W., Sec. 9—SW¼SE¼SW¼
Drainage Area: 1.43 square miles
Station Elevation: 25 feet
Mean Elevation: 557 feet
Remarks: Discharge measurements taken at outflow from a small pond immediately upstream.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
6/25	0.02	10/23	Dry
7/29	n.f.	11/21	Dry
8/26	n.f.	12/10	0.04
9/23	n.f.		

Station Number: O-14

Location: T. 36N., R. 1W., Sec. 2—SE¼NE¼NW¼. North of road above culvert in bend of road. Less than 0.1 mile from Doe Bay.
Draomage Area: 1.2 square miles
Station Elevation: 60 feet
Mean Elevation: 880 feet
Remarks: Recorded water rights allow 14 acre-feet per year to be diverted for irrigation and stock water use.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	12.67	7/29	0.02
2/26	3.45	8/27	t.
3/26	1.98	9/23	n.f.
4/23	0.98	10/22	n.f.
6/4	0.48	11/12	0.28
6/25	0.09	12/10	0.25

Station Number: O-15

Location: T. 37N., R. 1W., Sec. 36—SW¼NE¼NW¼. North of road above culvert 1.4 miles northeast of Doe Bay.
Drainage Area: 0.65 square mile
Station Elevation: 220 feet
Mean Elevation: 960 feet
Remarks: Water rights for 200 acre-feet per year permit diversion from a 19 acre reservoir for irrigation, recreation and general use. The reservoir is 0.6 mile upstream from the measurement site.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
1/29	5.92	7/29	t.
2/26	1.56	8/26	Dry
3/26	0.85	9/23	Dry
4/23	0.41	10/23	Dry
6/4	0.31	11/12	0.035
6/25	0.001	12/10	0.099

Station Number: OR-1 (Otter Creek)

Location: T. 37N., R. 1W., Sec. 31—SW¼NW¼NE¼. West of road and below culvert about 0.8 miles north of Rosario.
Drainage Area: 0.38 square mile
Station Elevation: 430 feet
Mean Elevation: 900 feet
Remarks: Flow measurement is discharge from Flaherty's Lake (surface area 2.5 acres).

Discharge Masurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/26	1.15	8/27	0.029
3/26	0.84	9/23	0.008
4/23	0.44	10/23	0.038
6/4	0.28	11/12	0.303
6/25	0.055	12/10	0.208
7/29	0.022		

Station Number: OR-2 (Cold Creek)

Location: T. 37N., R. 1W., Sec. 32—NE¼SW¼NW¼
Drainage Area: 1.17square miles
Station Elevation: 400 feet
Mean Elevation: 1365 feet
Remarks: No recorded diversions. Low flow maintained by springs.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/26	1.93	8/27	0.141
3/26	1.2	9/23	0.101
4/23	0.77	10/23	0.076
6/4	0.45	11&12	0.131
6/25	0.26	12/10	0.134
7/29	0.285		

Station Number: OK-1 (Keys Springs)

Location: T. 37N., R. 1W., Sec. 19–NE¼SW¼SW¼. Upstream from northern pond and below dirt road–about 2 miles from East Sound.
Drainage Area: 0.31 square mile
Station Elevation: 90 feet
Mean Elevation: 995 feet
Remarks: Base flow is discharge from several springs at the base of the steep grade to the east.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
7/18	0.789	10/23	0.455
7/29	0.657	11/12	0.490
8/27	0.526	12/10	0.408
9/23	0.452		

Station Number: OK-2 (Keys Springs)

Location: T. 37N., R. 1W., Sec. 19–SW¼SW¼SW¼. In dug channel between two ponds.
Drainage Area: 0.12 square mile
Station Elevation: 100 feet
Mean Elevation: 800 feet
Remarks: Discharge from upper pond to lower pond.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
7/19	0.195	10/23	0.066
7/29	0.143	11/12	0.203
8/27	0.103	12/10	0.096
9/23	0.060		

Station Number: OK-3 (Keys Springs)

Location: T. 37N., R. 1W., Sec. 24–NE¼SE¼SE¼. West of above road.
Drainage Area: 0.47 square mile
Station Elevation: 50 feet
Mean Elevation: 911 feet
Remarks: Small amount of diversion to single house. OK-1 and OK-2 discharge into pond immediately upstream.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
7/29	0.532	10/23	0.352
8/27	0.454	11/12	0.343
9/23	0.272	12/10	0.173

LOPEZ ISLAND

Station Number: L-1

Location: T. 34N., T. 2W., Sec. 11–SW¼NE¼NW¼. At north end of culvert at intersection of two roads–0.6 miles north of Richardson.
Drainage Area: 4.40 square miles
Station Elevation: 45 feet
Mean Elevation: 293 feet
Remarks: 11 artificial impoundments with a total surface area of 7.5 acres located upstream on main channel. Total of 21 dams in the watershed. The largest impoundment (3.9 acres) is about 2000 feet from the station. Low flow is controlled by seepage from dams. Recorded water rights allow diversions totaling 81 acre-feet per year.

Discharge measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/25	3.10	7/31	n.f.
3/28	0.74	8/24	Dry
4/25	0.096	9/24	Dry
6/6	t.	10/21	Dry
6/26	t.	11/10	Dry
7/16	t.	12/10	0.02

Estimated Mean Monthly Discharge for 1974 (cfs)

Month	*Amount*	*Month*	*Amount*
January	6.6	July	0.0
February	2.0	August	0.0
March	0.4	September	0.0
April	0.03	October	0.0
May	0.001	November	0.0
June	0.001	December	0.01

Station Number: L-2

Location: T. 34N., R. 2W., Sec. 3–SW¼SW¼SE¼, Just upstream from culvert under road, 1.3 miles from Richardson and 0.9 mile south of cemetery.
Drainage Area: 2.02 square miles
Station Elevation: 50 feet
Mean Elevation: 173 feet
Remarks: 3 impoundments totaling less than 0.4 surface acres located upstream on main channel, 8 impoundments in the watershed. Low flow derived primarily from springs located immediately above station.

Discharge Measurements in 1974 (cfs)

Date	*Amount*	*Date*	*Amount*
2/25	1.02	7/31	0.003
3/28	0.40	8/26	0.002
4/25	0.14	9/24	0.009
6/6	0.01	10/21	0.01
6/26	0.01	11/10	0.01
7/16	0.02	12/10	0.01

Estimated Mean Monthly Discharge (cfs)*1974

Island and	*Site No.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Drainage Area (sq. mi.)*
Orcas	2	1.8	1.1	0.57	0.20	0.07	0	0	0	0	0.01	0.13	0.90
	3A	0.22	0.11	0.01	0	0	0	0	0	0	0	0.01	0.10
	4	1.0	0.5	0.21	0.06	0.02	0	0	0	0	0.008	0.04	0.49
	5	4.0	2.4	1.2	0.46	0.19	0.03	0.01	0.008	0.01	0.03	0.30	1.62
	6	3.2	1.5	0.56	0.11	0.04	0.03	0	0.03*	0.08*	0.04	0.11	1.64
	7	11.6	5.9	2.5	0.60	0.09	(T)	0	0	0	0.02	0.29	5.04
	8	5.1	2.9	1.3	0.27	0.04	(T)	0	0	0.001	0.02	0.12	2.68
	9†	1.93	1.48	0.48	0.14	0.03	0	0	0	0	0	0.075	0.93
	11	2.0	1.1	0.54	0.32	0.22	0.08	0.01	0.0008	0.0007	0.015	0.25	1.29
	12	7.8	6.2	4.2	2.8	1.8	0.70	0.45	0.23	0.23	0.44	2.2	3.17
	13	2.3	1.3	0.70	0.28	0.09	0	0	0	0	0.04	0.18	1.43
	14	4.6	3.2	1.5	0.62	0.26	0.05	0	0	0	0.11	0.32	2.10
	15	2.1	1.3	0.74	0.27	0.07	(T)	0	0	0	0.03	0.16	0.65
	R1	1.8	1.1	0.63	0.29	0.13	0.04	0.02	0.01	0.03	0.10	0.34	0.38
	R2	3.6	1.8	0.94	0.52	0.35	0.27	0.15	0.11	0.08	0.10	0.20	1.17
San Juan	1	2.1	1.0	0.32	0.03	0.004	0.001	0	0	0	0.003	0.015	0.85
	4†	2.64	1.34	0.54	0.12	0.015	0	0	0	0	0.003	0.055	1.76
	5	0.43	0.24	0.09	0.02	0.002	0	0	0	0	0	0.008	0.24
	6	1.2	0.64	0.31	0.10	0.02	0.007	0.001	0	0.0005	0.013	0.056	0.75
	9	9.8	4.9	2.0	9.42	0.04	0	0	0	0	0	0.075	3.83
	10	10	4.3	1.4	0.22	0.015	0	0	0	0	0.003	0.08	3.45
	11A	0.67	0.34	0.10	0.015	0.008	0.002	0.0006	0.0005	0.0009	0.008	0.012	0.44
	12	21	10	1.1	0.11	0.03	0	0.07*	0.05*	0.10*	0.40	0.9	13.90
	13	0.84	0.42	0.13	0.002	0	0	0	0	0	0	0	0.63
	14	3.4	1.7	0.48	0.03	0.001	0	0	0	0	0	0.005	1.52
Lopez	1	6.6	2.0	0.4	0.03	0.001	0.001	0	0	0	0	0.007	4.40
	2	2.1	0.88	0.28	0.04	0.01	0.01	0.01	0.009	0.008	0.009	0.01	2.02

† Gaging station at which daily flows were obtained.
* Irrigation discharge.

O-9: Staff Gage Measurements
Discharge in Cubic Feet per Second in 1974

Day	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1	3.9	1.3	0.6	0.3	0.06	0	0	0	0	0	0
2	3.4	1.5	0.5	0.3	0.06	0	0	0	0	0	0
3	3.3	1.5	0.6	0.2	0.06	0	0	0	0	0	0
4	3.5	1.6	0.6	0.2	0.06	0	0	0	0	0	0
5	3.4	1.9	0.8	0.2	0.08	0	0	0	0	0	0
6	3.1	1.9	0.9	0.2	0.08	0	0	0	0	0	0
7	3.0	1.9	0.8	0.2	0.06	0	0	0	0	0	0
8	2.6	1.8	0.8	0.2	0.06	0	0	0	0	0	0
9	2.4	1.6	0.6	0.2	0.04	0	0	0	0	0	0
10	2.1	1.6	0.8	0.2	0.04	0	0	0	0	0	0
11	2.1	1.6	0.8	0.2	0.03	0	0	0	0	0	0
12	1.6	1.5	0.6	0.2	0.03	0	0	0	0	0	0
13	1.6	1.3	0.5	0.2	0.03	0	0	0	0	0	0
14	1.5	1.5	0.5	0.2	0.02	0	0	0	0	0	0
15	1.3	1.6	0.4	0.1	0.02	0	0	0	0	0	0
16	1.2	1.8	0.3	0.1	0.02	0	0	0	0	0	0
17	1.0	1.9	0.3	0.1	0.01	0	0	0	0	0	0
18	1.0	1.9	0.3	0.1	0.01	0	0	0	0	0	0
19	1.2	1.9	0.3	0.1	0.01	0	0	0	0	0	0
20	1.0	1.8	0.3	0.08	0.01	0	0	0	0	0	0
21	1.3	1.6	0.3	0.08	0	0	0	0	0	0	0.01
22	1.3	1.5	0.3	0.08	0	0	0	0	0	0	0.01
23	1.2	1.3	0.3	0.08	0	0	0	0	0	0	0.01
24	1.2	1.2	0.3	0.08	0	0	0	0	0	0	0
25	1.3	1.2	0.3	0.08	0	0	0	0	0	0	0
26	1.3	1.0	0.3	0.1	0	0	0	0	0	0	0
27	1.3	1.2	0.3	0.1	0	0	0	0	0	0	0
28	1.3	1.0	0.3	0.09	0	0	0	0	0	0	0.2
29		0.9	0.3	0.08	0	0	0	0	0	0	0.4
30		0.8	0.3	0.08	0	0	0	0	0	0	0.7
31		0.8		0.06		0	0		0		1.0
Mean	1.93	1.48	0.48	0.14	0.026	0	0	0	0	0	0.075
Runoff (inches)	2.16	1.84	0.58	0.18	0.032						0.093
Runoff Acre-feet	107	91	28.6	8.91	1.57						4.62

O-9: Staff Gage Measurements
Discharge in Cubic Feet per Second
First Quarter of 1975

Day	*January*	*February*	*March*
1	1.2	1.3	2.1
2	1.0	1.0	2.0
3	1.0	0.91	1.9
4	1.0	0.91	1.7
5	1.2	0.84	1.5
6	1.2	0.71	1.4
7	1.2	0.98	1.3
8	1.1	1.0	1.3
9	1.1	1.2	1.3
10	1.0	1.3	1.2
11	.98	1.3	1.2
12	2.3	1.6	1.0
13	3.1	2.3	0.91
14	3.3	3.0	0.77
15	3.1	2.8	0.77
16	3.3	2.6	0.77
17	3.7	2.4	0.77
18	5.8	2.4	0.71
19	4.8	2.3	0.71
20	4.2	2.4	0.65
21	3.3	2.6	0.65
22	2.8	2.4	0.53
23	2.8	2.3	0.53
24	2.6	2.4	0.47
25	2.4	2.6	0.42
26	2.3	2.4	0.38
27	1.9	2.3	0.34
28	1.8	2.1	0.30
29	1.6		0.26
30	1.5		0.26
31	1.4		0.26
Mean	2.26	1.87	0.92
Runoff (inches)	2.80	2.09	1.14
Runoff (acre-ft)	139.	104.	56.

SJ-4: Staff Gage Measurements
Discharge in Cubic Feet Per Second in 1974

Day	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1	5.5	0.96	0.96	0.18	0.01	0	0	0	0	0	0
2	6.1	0.96	1.3	0.16	0.02	0	0	0	0	0	0
3	11	0.92	0.88	0.16	0.05	0	0	0	0	0	0
4	7.7	9.96	0.84	0.13	0.10	0	0	0	0	0	0
5	4.7	1.0	1.9	0.13	0.09	0	0	0	0	0	0
6	3.5	1.1	0.96	0.11	0.05	0	0	0	0	0	0.01
7	2.9	0.96	0.84	0.16	0.04	0	0	0	0	0	0
8	2.6	0.88	0.75	0.13	0.02	0	0	0	0	0	0
9	2.4	0.79	0.71	0.11	0.02	0	0	0	0	0	0
10	2.1	0.71	0.62	0.11	0.02	0	0	0	0	0	0
11	1.8	0.71	0.54	0.47	0.01	0	0	0	0	0.01	0.01
12	1.6	0.92	0.50	0.32	0.01	0	0	0	0	0.02	0
13	1.4	1.6	0.41	0.27	0	0	0	0	0	0.01	0
14	1.7	1.0	0.41	0.24	0	0	0	0	0	0	0
15	1.6	5.3	0.38	0.16	0	0	0	0	0	0	0
16	1.5	5.4	0.35	0.13	0	0	0	0	0	0	0.01
17	1.6	3.1	0.29	0.11	0	0	0	0	0	0.01	0.01
18	1.4	2.2	0.29	0.09	0	0	0	0	0	0.01	0.01
19	1.3	1.7	0.24	0.26	0	0	0	0	0	0.01	0.02
20	1.2	1.2	0.24	0.05	0	0	0	0	0	0.01	0.04
21	1.1	1.0	0.24	0.04	0	0	0	0	0	0.01	0.07
22	1.2	0.96	0.24	0.04	0	0	0	0	0	0	0.02
23	1.3	0.88	0.29	0.04	0	0	0	0	0	0	0.01
24	1.3	0.84	0.27	0.04	0	0	0	0	0	0	0.01
25	1.3	0.79	0.27	0.06	0	0	0	0	0	0	0.01
26	1.4	0.88	0.35	0.05	0	0	0	0	0	0	0.01
27	1.4	0.88	0.32	0.04	0	0	0	0	0	0	0.01
28	1.2	0.88	0.29	0.02	0	0	0	0	0	0	0.13
29		0.80	0.24	0.02	0	0	0	0	0	0	0.29
30		0.70	0.20	0.02	0	0	0	0	0	0	0.50
31		0.62		0.01		0	0		0		0.54
Mean	2.64	1.34	0.54	0.12	0	0	0	0	0	0.003	0.055
Runoff (inches)	1.56	0.86	0.34	0.08						0.002	0.036
Runoff (acre-ft)	146	325	32	7.26						0.18	3.39

SJ-4: Staff Gage Measurements
Discharge in Cubic Feet per Second
First Quarter of 1975

Day	*January*	*February*	*March*
1	0.79	0.88	2.4
2	0.79	0.79	2.0
3	0.79	0.71	1.7
4	0.88	0.71	1.4
5	1.2	0.58	1.3
6	1.0	0.47	1.0
7	0.88	3.1	0.96
8	0.88	1.0	0.88
9	0.79	1.0	1.2
10	0.62	1.2	0.96
11	0.54	1.6	0.88
12	9.5	8.6	0.79
13	4.7	8.1	0.71
14	3.6	4.2	0.62
15	2.5	3.5	0.62
16	2.6	3.1	1.0
17	7.4	2.5	0.92
18	4.1	2.0	1.18
19	3.0	6.4	1.4
20	2.6	4.0	1.0
21	2.2	2.7	0.88
22	1.7	2.2	0.71
23	3.7	3.5	0.62
24	3.0	4.0	0.54
25	1.7	2.7	0.47
26	1.4	2.4	0.41
27	1.0	2.2	0.35
28	1.4	1.7	0.32
29	1.0		0.29
30	1.0		0.35
31	0.96		0.29
Mean	2.20	2.71	0.91
Runoff (inches)	1.44	1.60	0.59
Runoff (acre-ft)	135	150	56

APPENDIX D

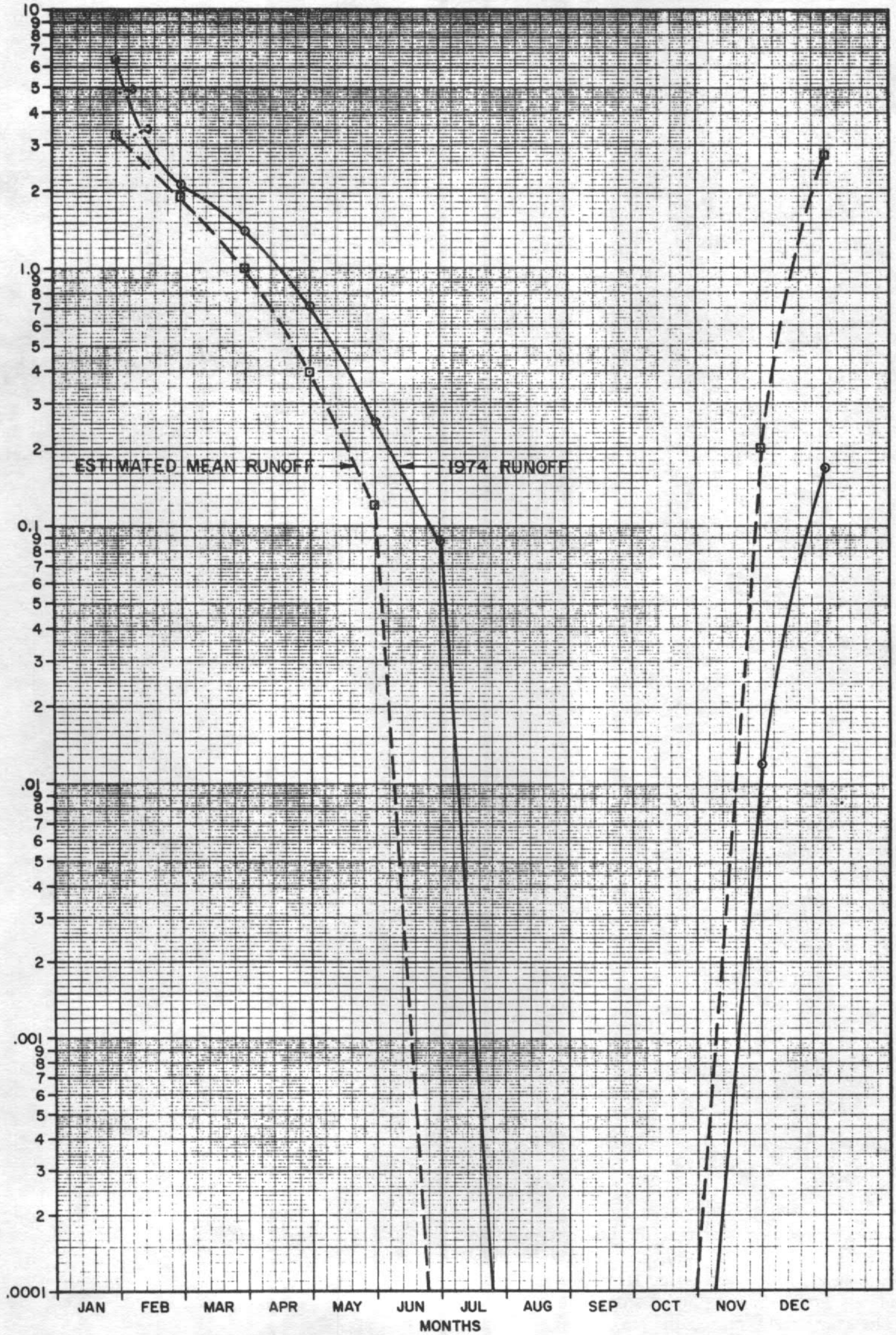
Runoff Hydrographs for 1974 and an Average Year

The following is a graphical presentation of the approximate monthly discharges of 1974 and the estimated mean runoff for the measurement sites described in the text. Monthly discharges were approximated by developing rating curves between discharges at the once-a-month measurement stations and the staff gage stations at which once-daily measurements were made (O-9, SJ-4). (Results are listed in Appendix C). Since storm flows can be partially to completely missed by once-a-day staff gage readings, this method generally underestimates runoff.

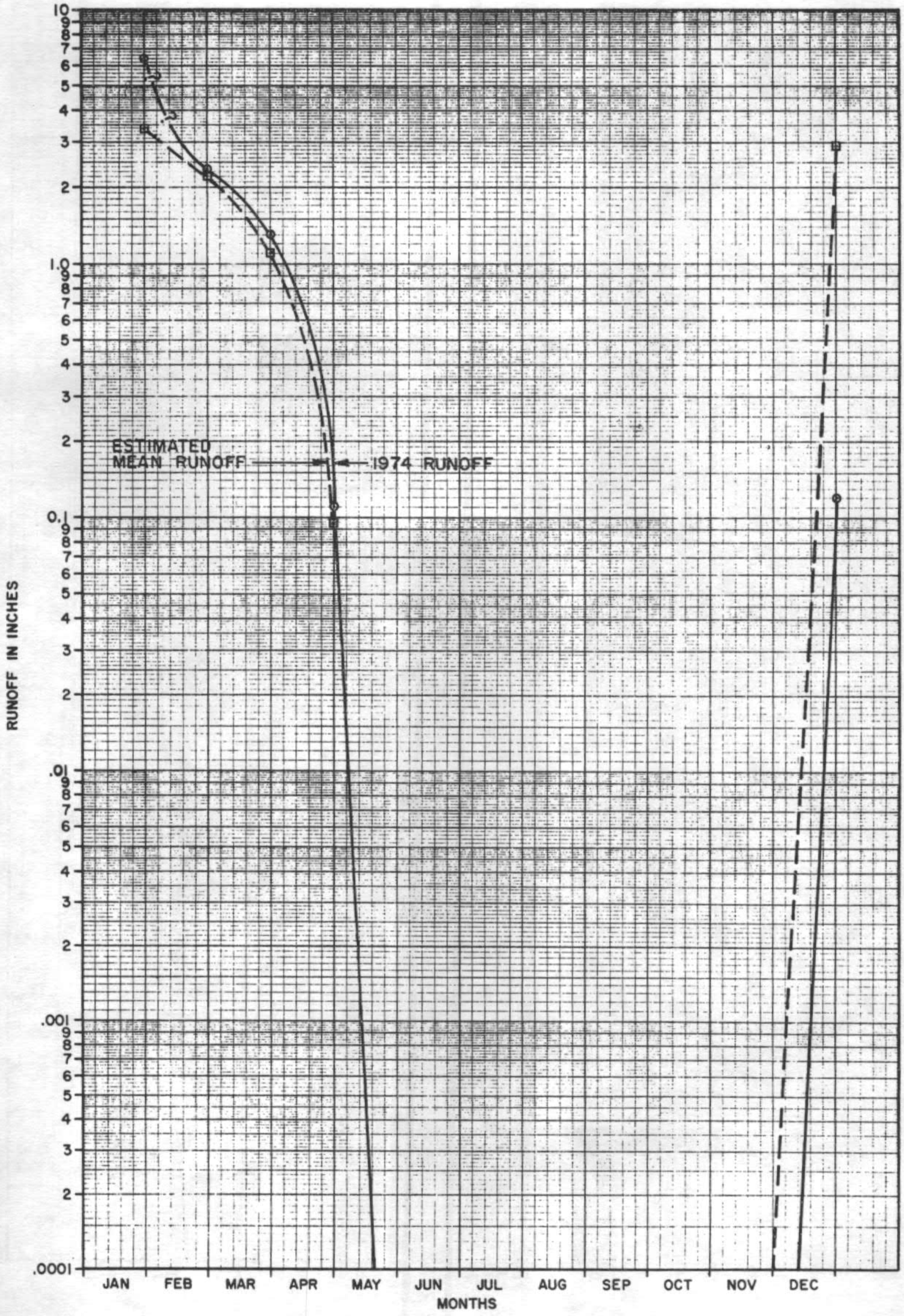
Comparisons of estimated monthly runoff with estimated monthly rainfall and evapotranspiration data for 1974 indicate that the discharge estimates are probably fairly accurate for February through September or October. January runoff was not measured. Discharge estimates for November and December of 1974 are probably low because stream flow measurements were made before most of the rain for each of the months had fallen, and because much of the high storm runoff was not measured by once-daily staff gage readings at the two stations.

Mean monthly runoff was estimated from average annual precipitation (Figure 1) by the Thornthwaite and Mather (1957) method, and was modified to fit the general shape of the monthly hydrograph of the 1974 runoff. Total annual runoff predicted by the Thornthwaite-Mather method is probably within ± 20% of actual measurements, based on comparison with 1974 runoff measurements. For October, November and December, the estimated mean runoff is probably less accurate because this method does not allow for storm runoff before the soils in the entire watershed are fully saturated. Storm runoff for these months was estimated by approximating that 5-10% of the watershed surface area was saturated in October, November and December (Dunne, 1970).

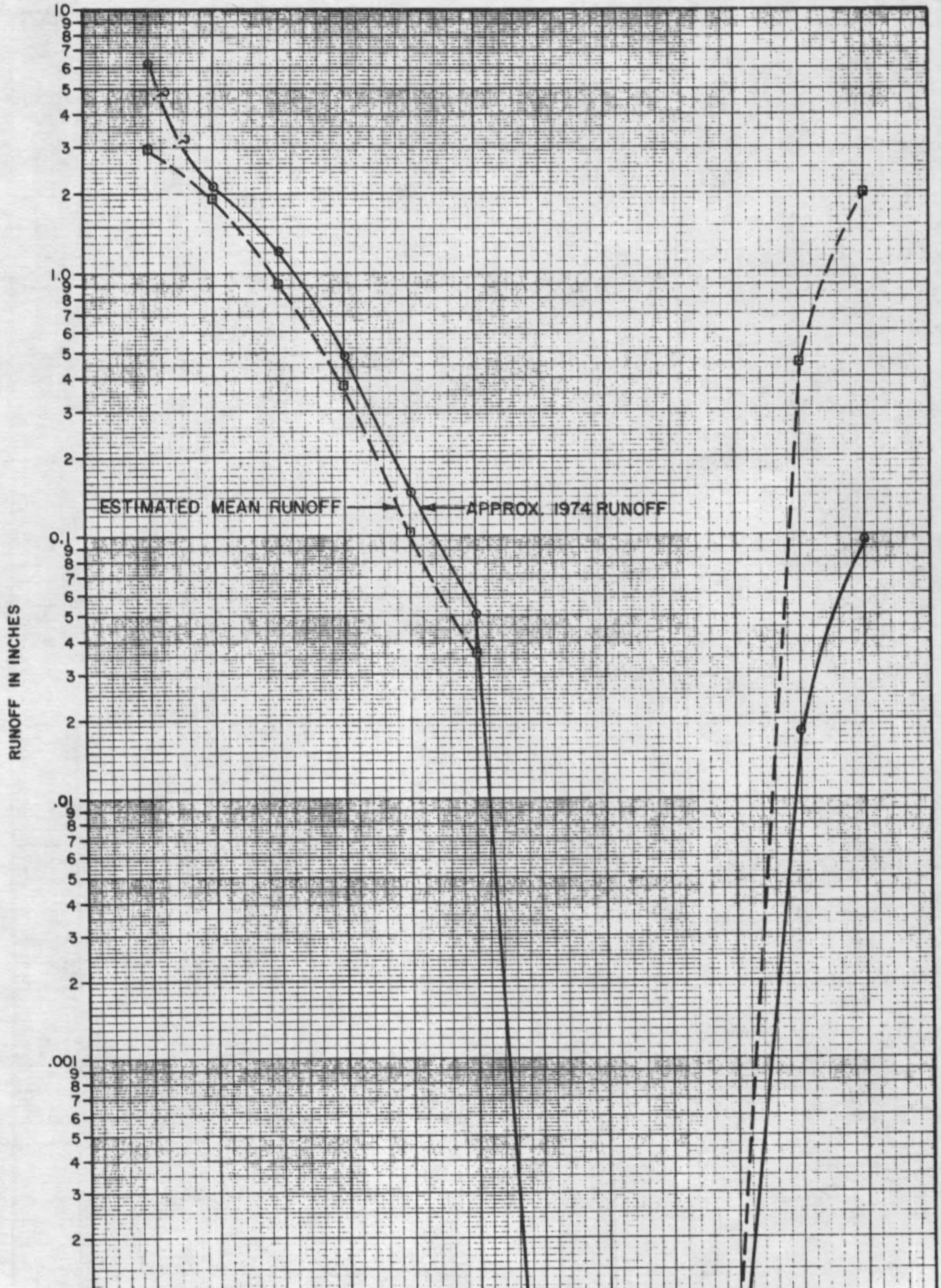
Several of the watersheds have reservoirs or lakes upstream from the measurement station. These ponds tend to redistribute runoff over larger time periods such that runoff in the wet season will be less than expected and in the dry season it will be more than expected. This variation makes runoff estimates based on once-a-month stream discharge measurements less accurate.


10
9
8
7
6
5
4
3
2
1.0
0.1
.01
.001
.0001
RUNOFF IN INCHES
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 2

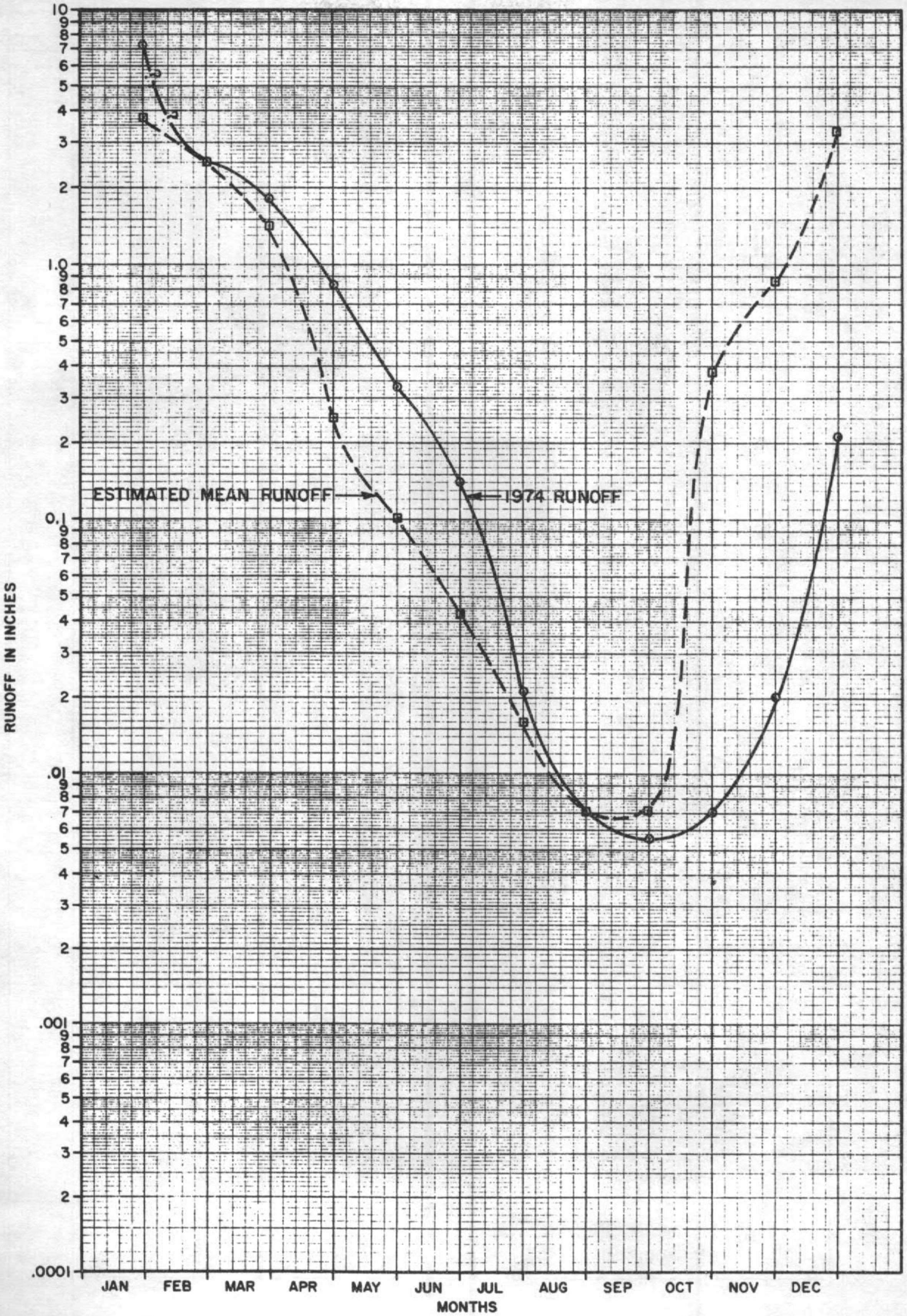

RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED
MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 3A

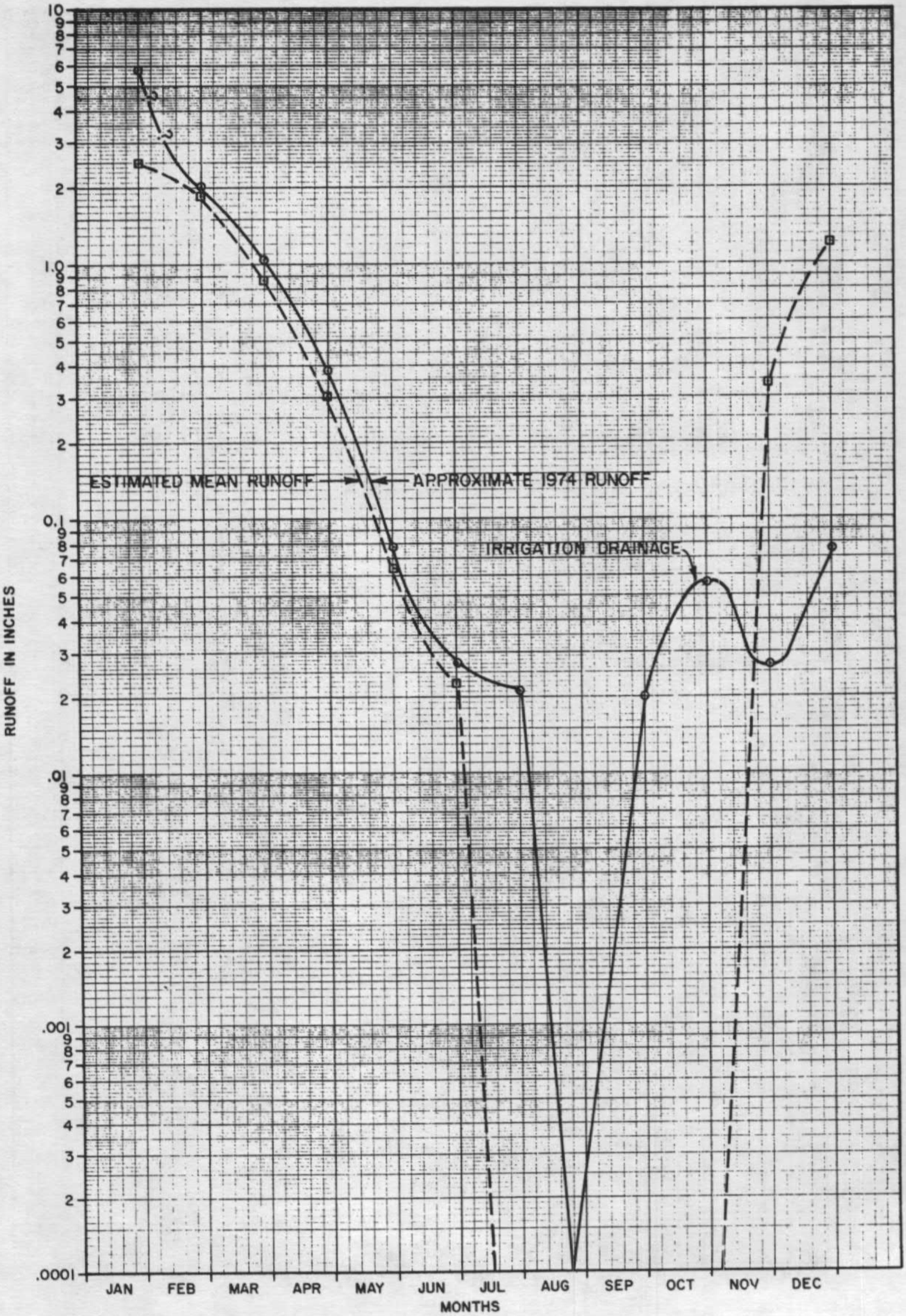


ESTIMATED MEAN RUNOFF
APPROX. 1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 4

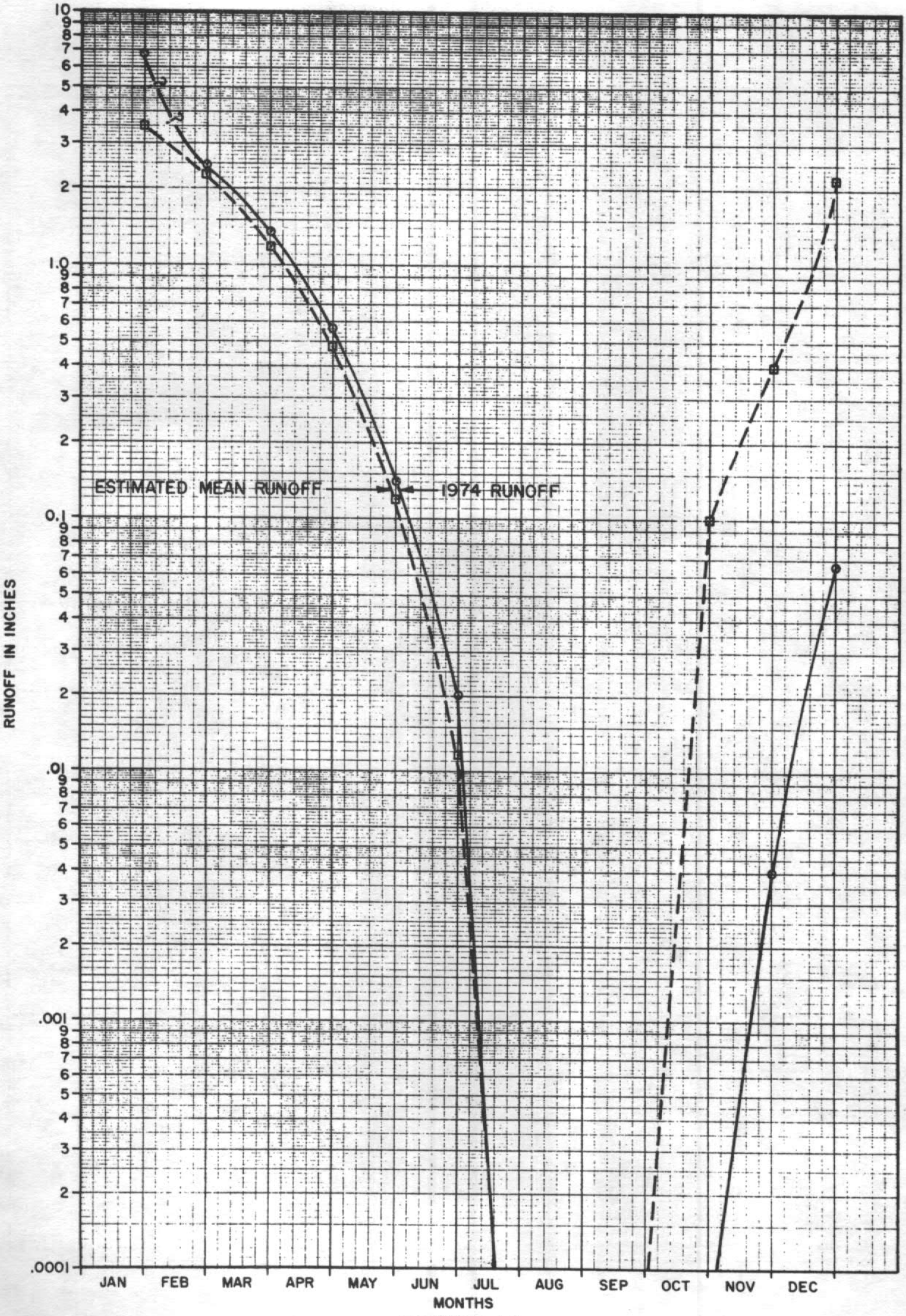

10
9
8
7
6
5
4
3
2
1.0
0.1
.01
.001
.0001
RUNOFF IN INCHES
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 5



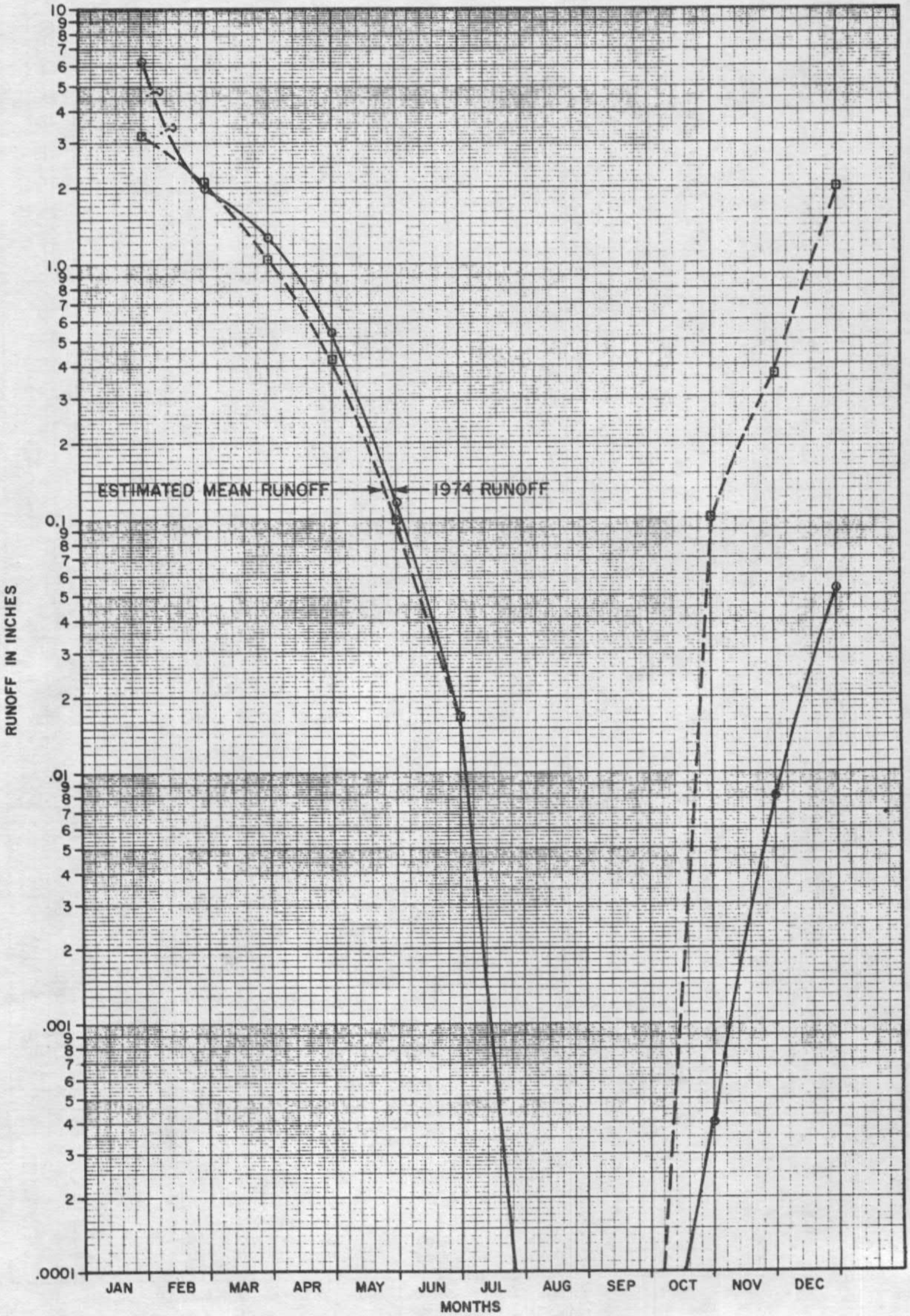
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
APPROXIMATE 1974 RUNOFF
IRRIGATION DRAINAGE
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 6



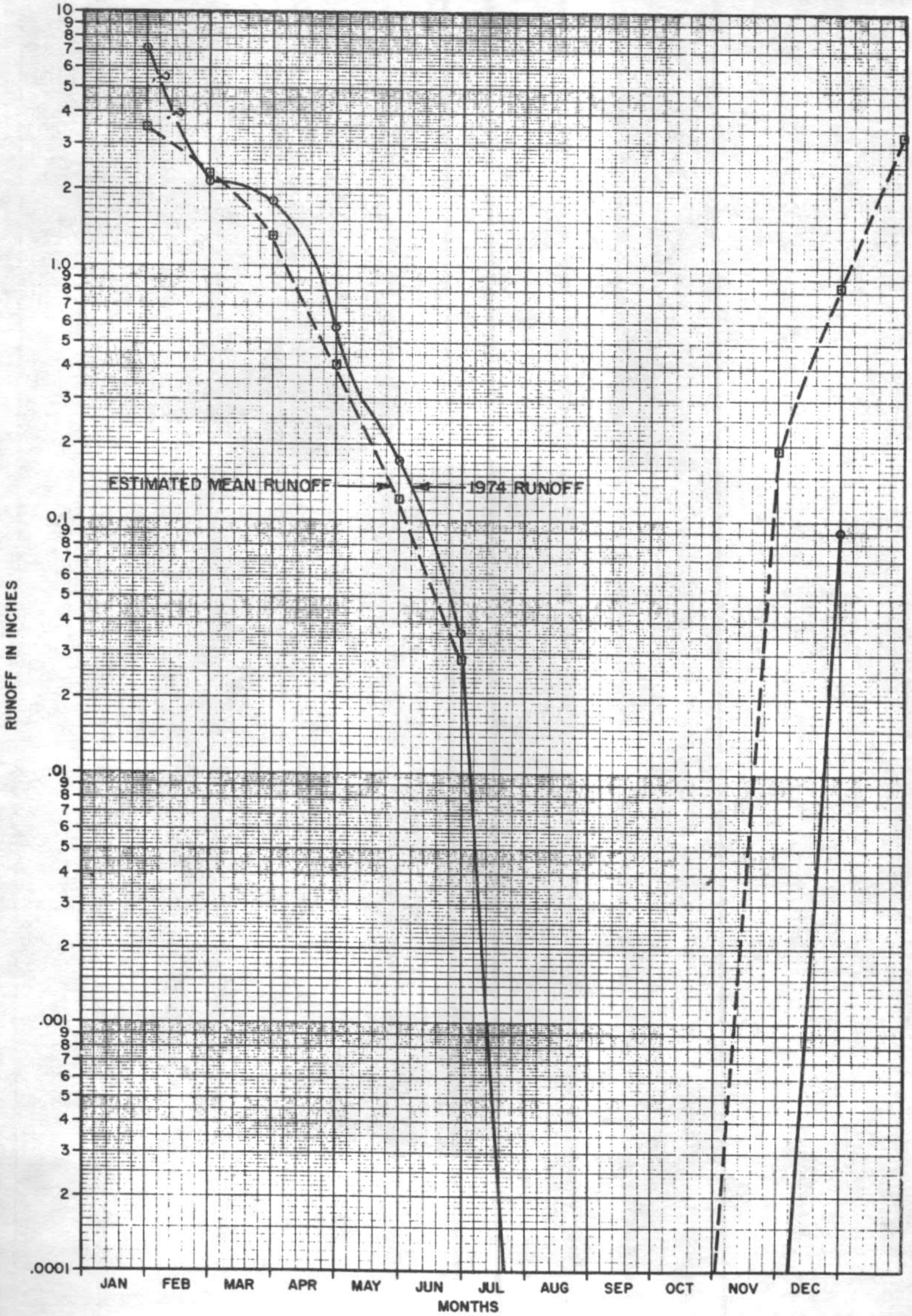
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 7

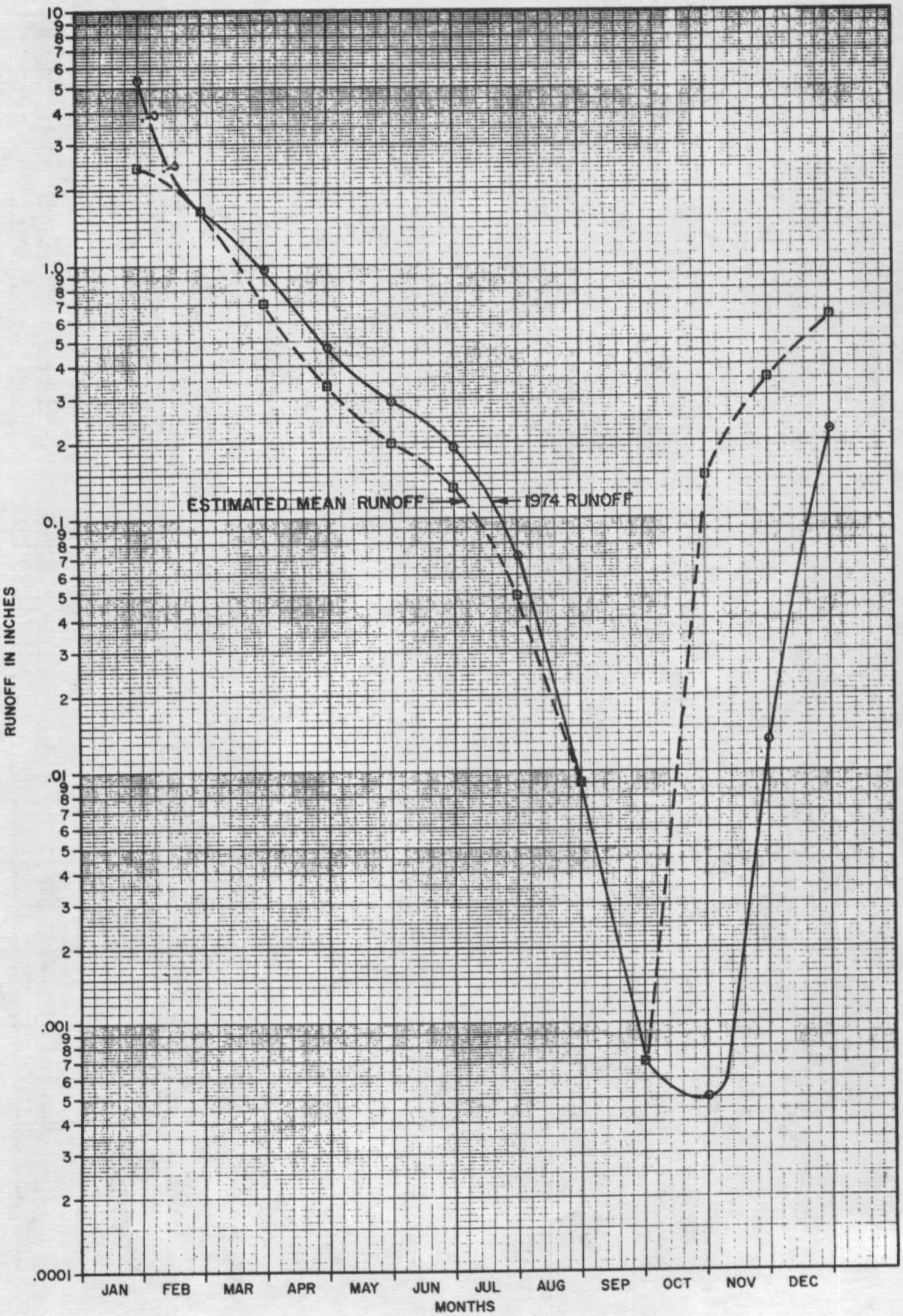


RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

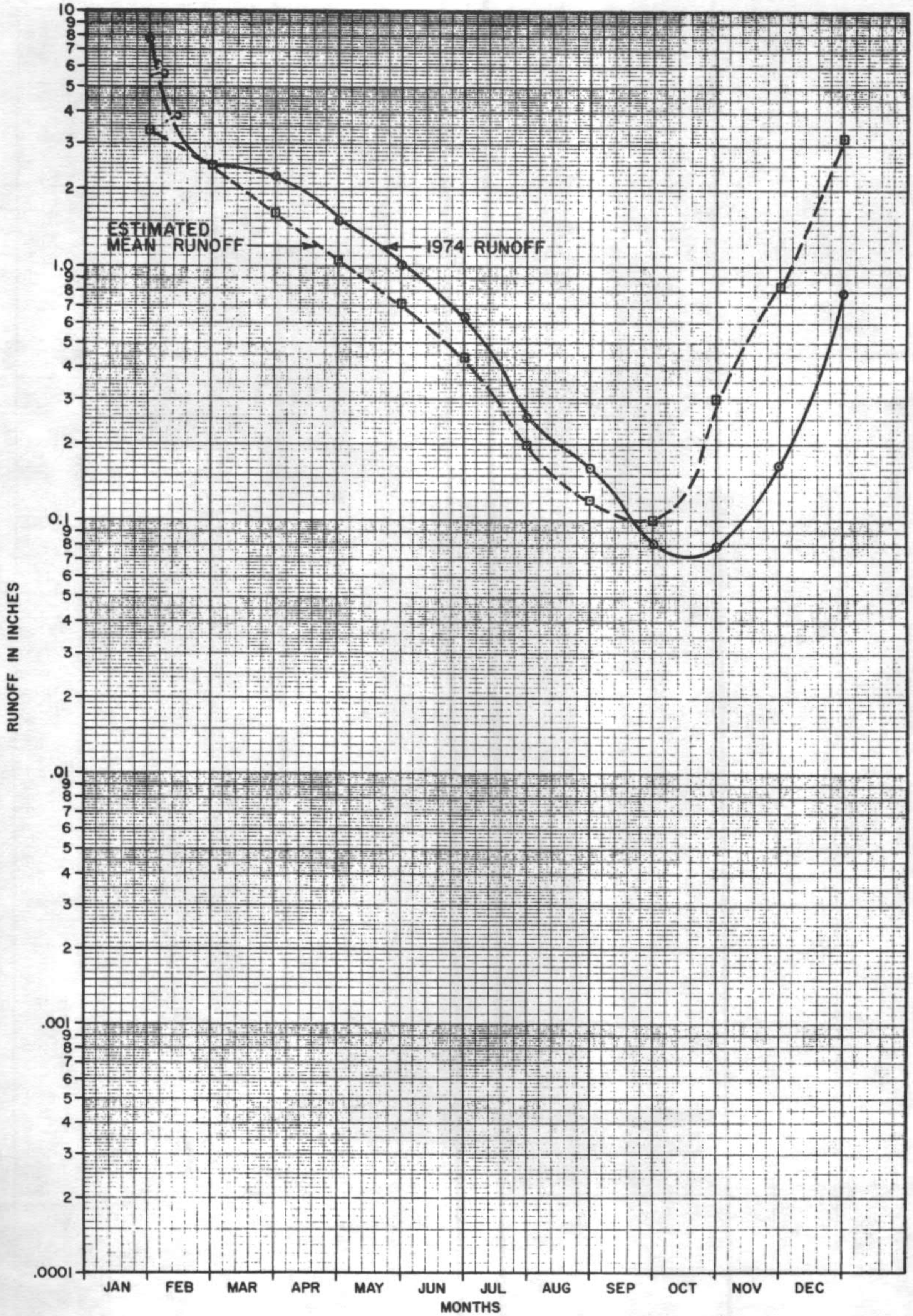
ORCAS 8


ESTIMATED MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

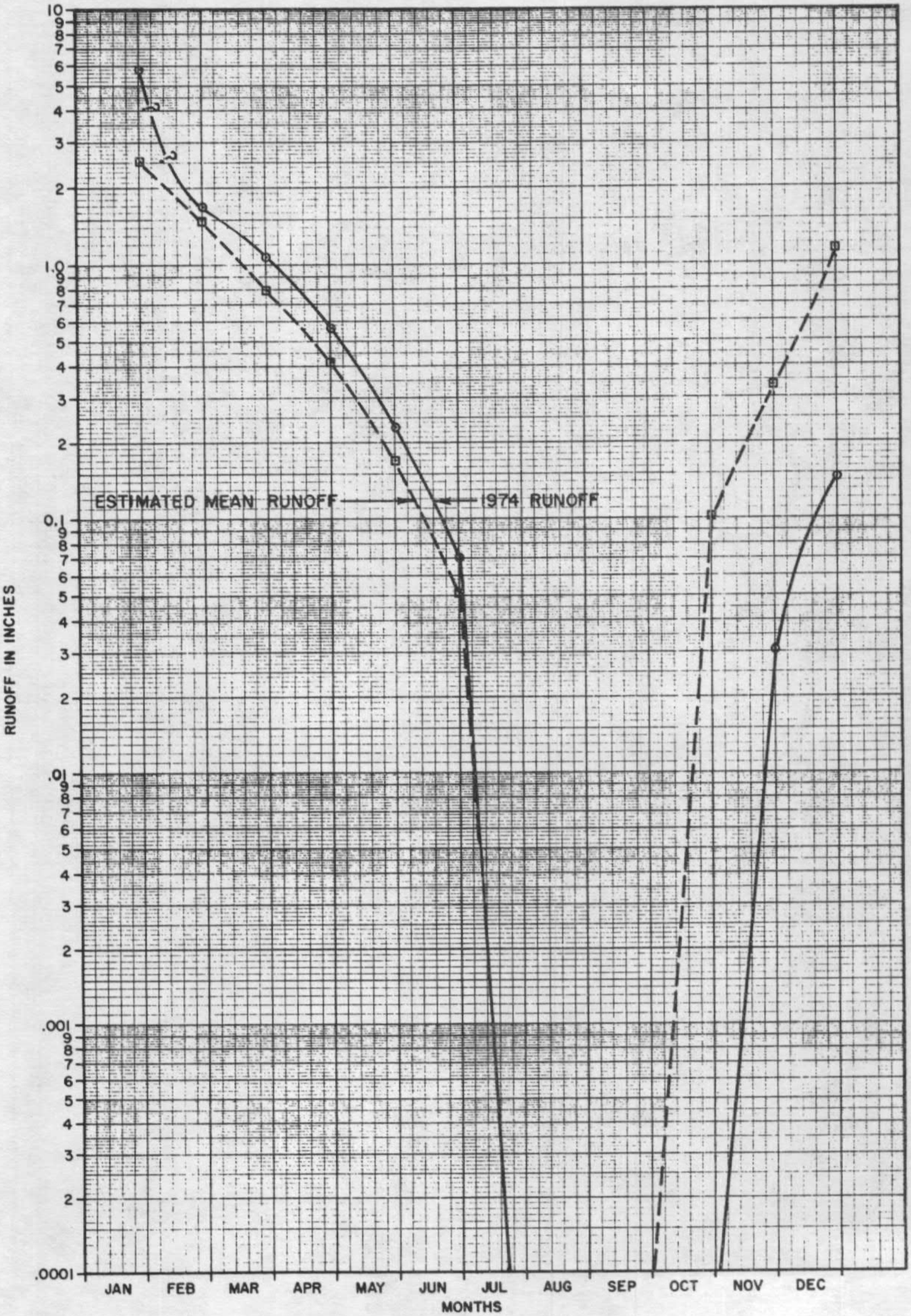
ORCAS 9


RUNOFF IN INCHES
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS II

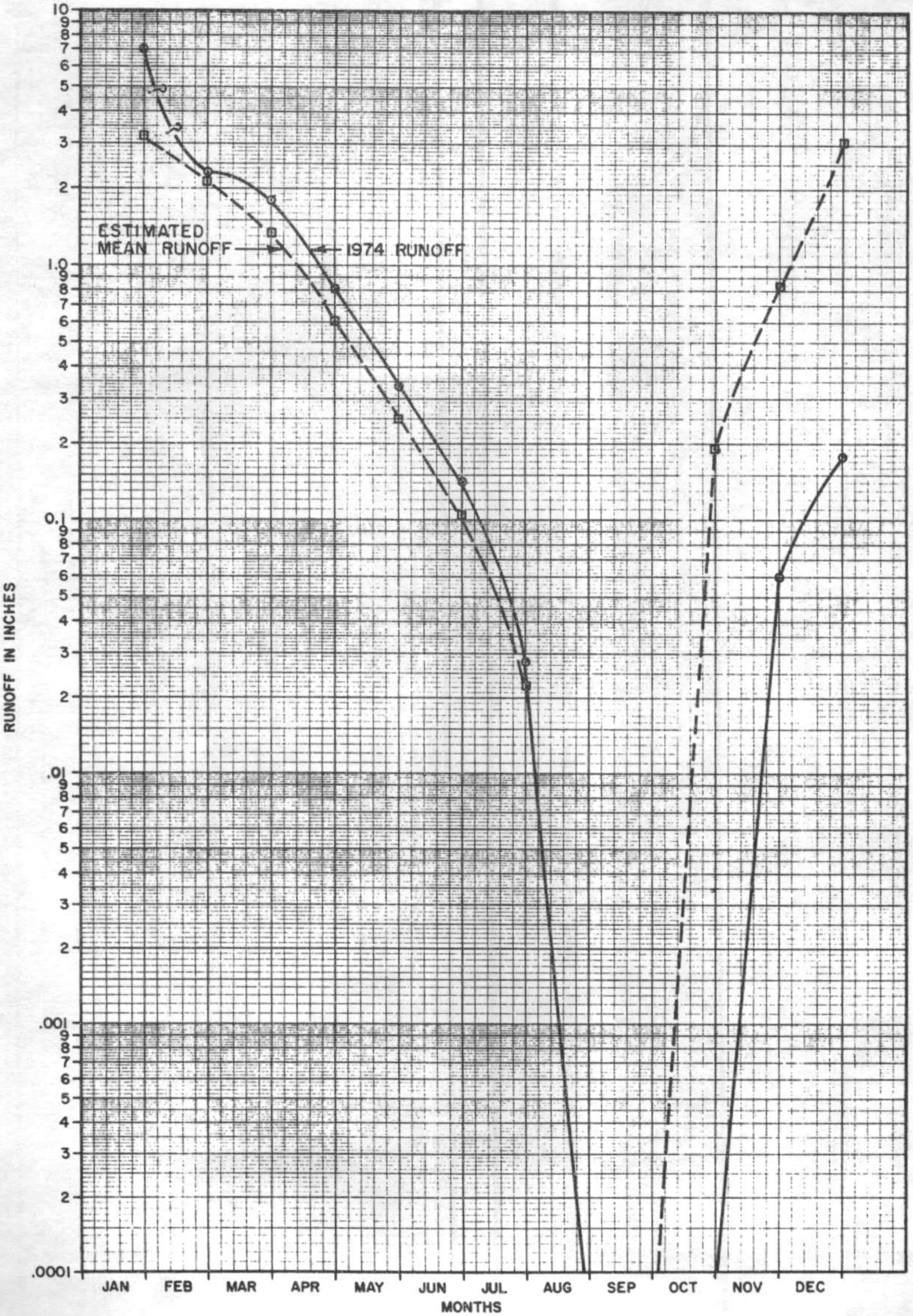

10
9
8
7
6
5
4
3
2
1.0
0.1
.01
.001
.0001
RUNOFF IN INCHES
ESTIMATED
MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 12

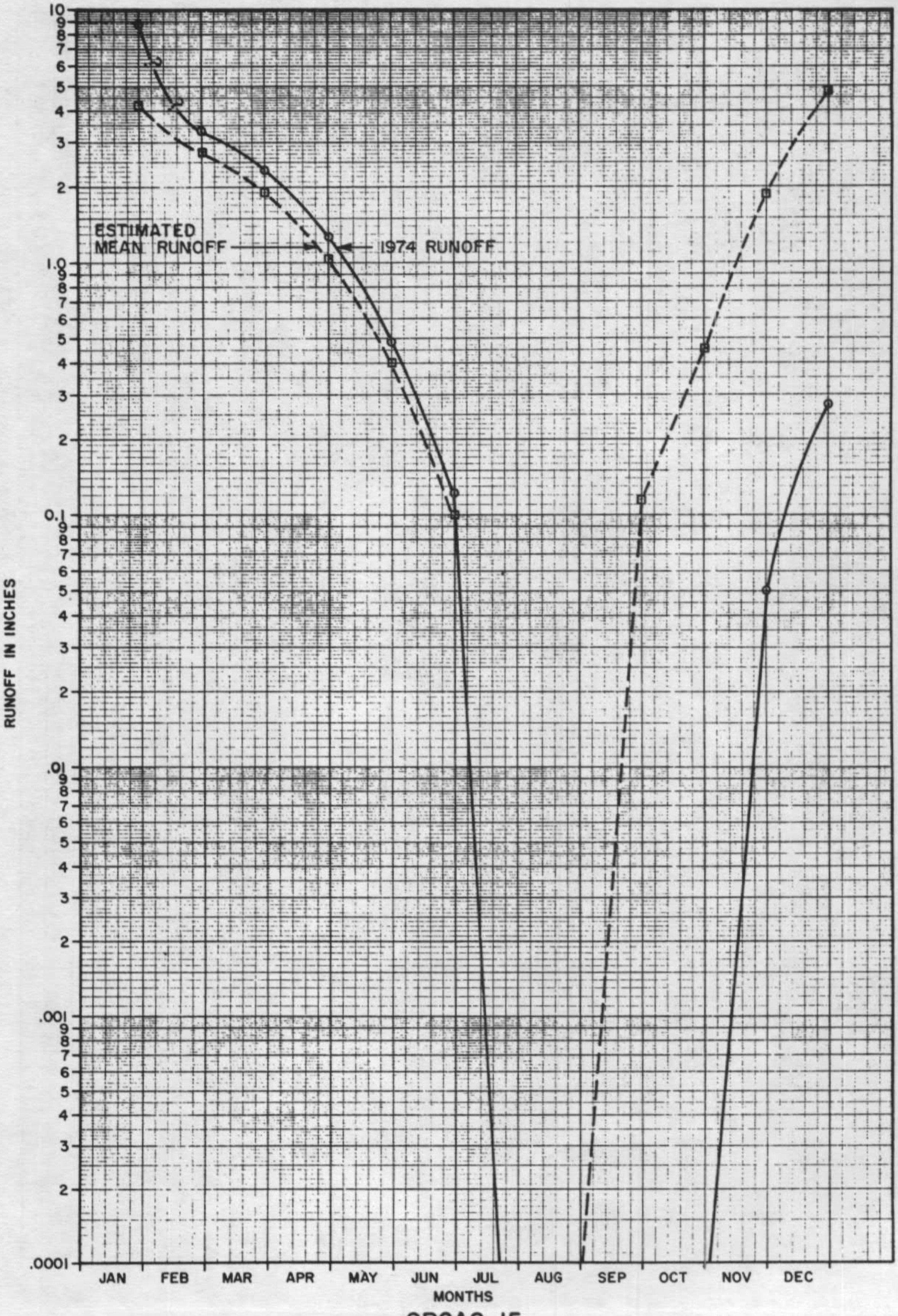


RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

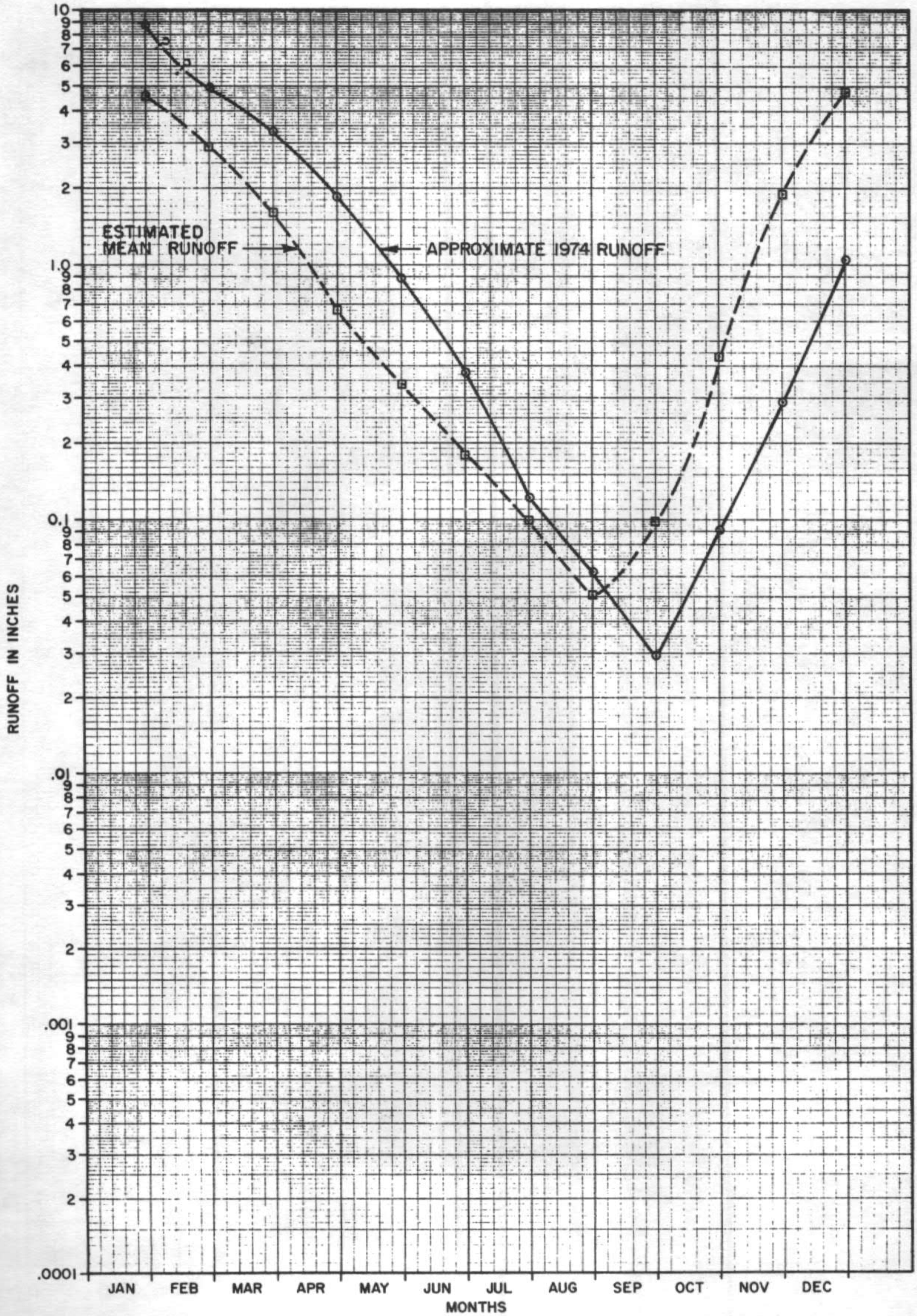
ORCAS 13


ESTIMATED MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS

ORCAS 14

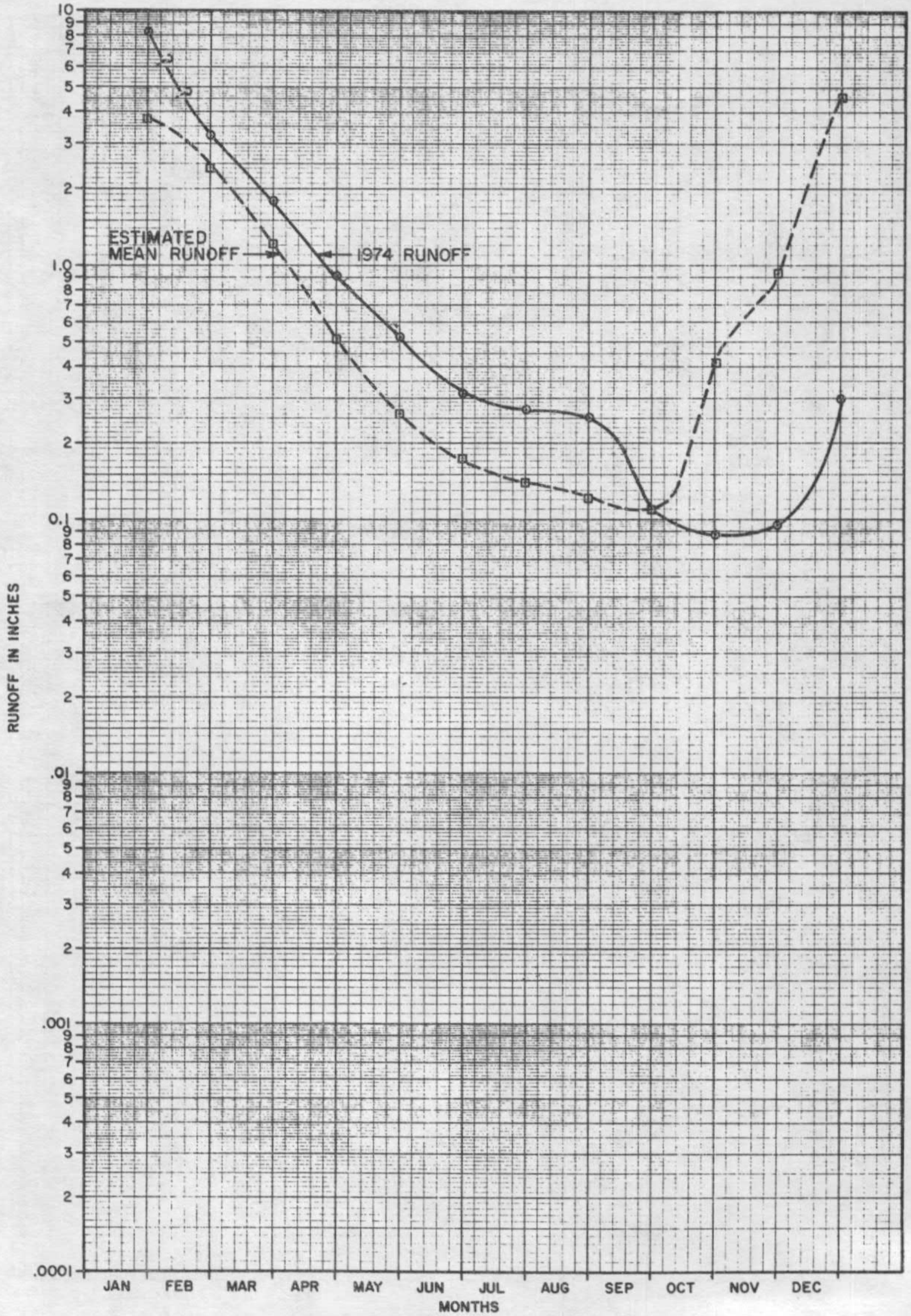

RUNOFF IN INCHES
ESTIMATED
MEAN RUNOFF
1974 RUNOFF
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS 15

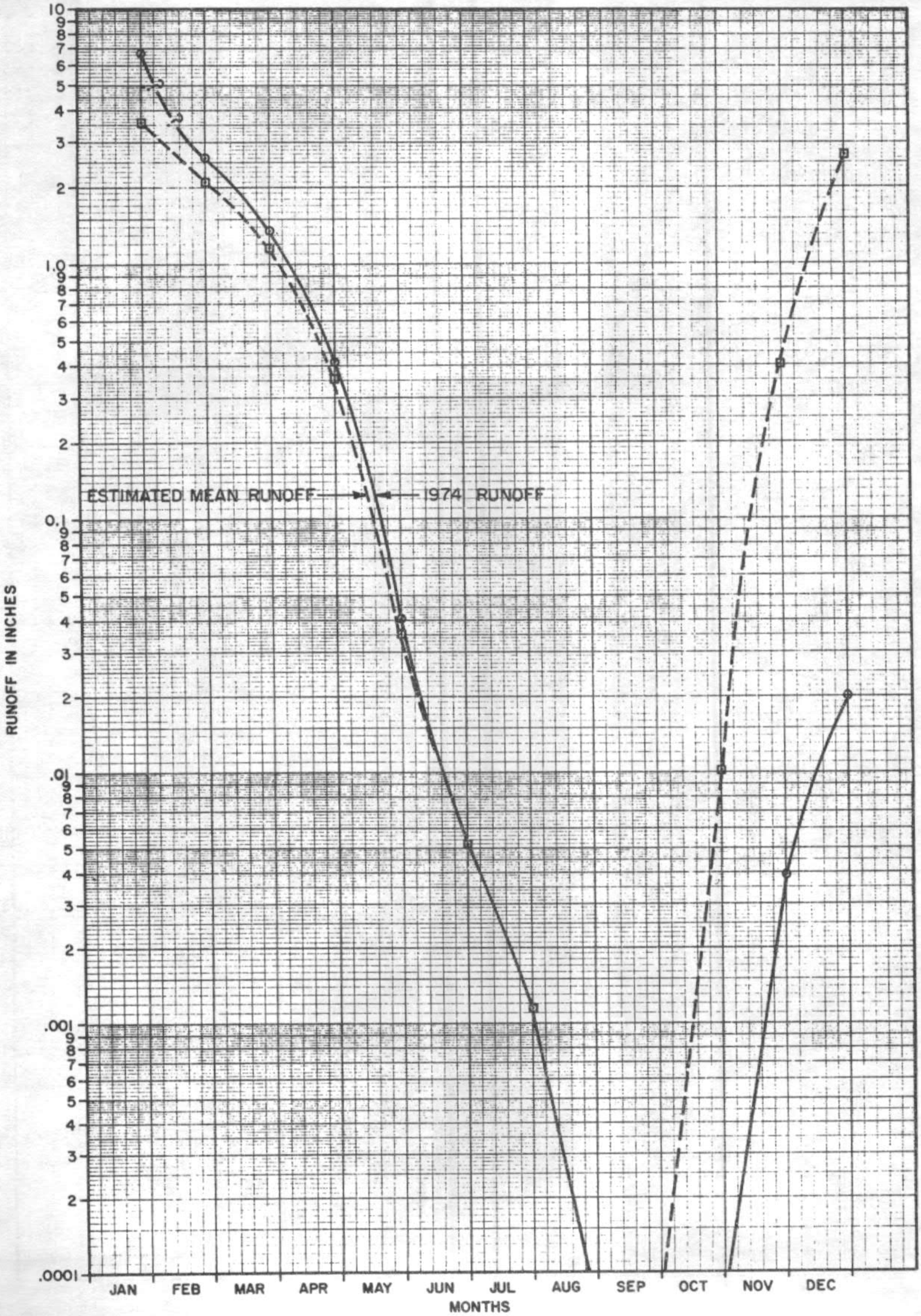


ESTIMATED MEAN RUNOFF
APPROXIMATE 1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

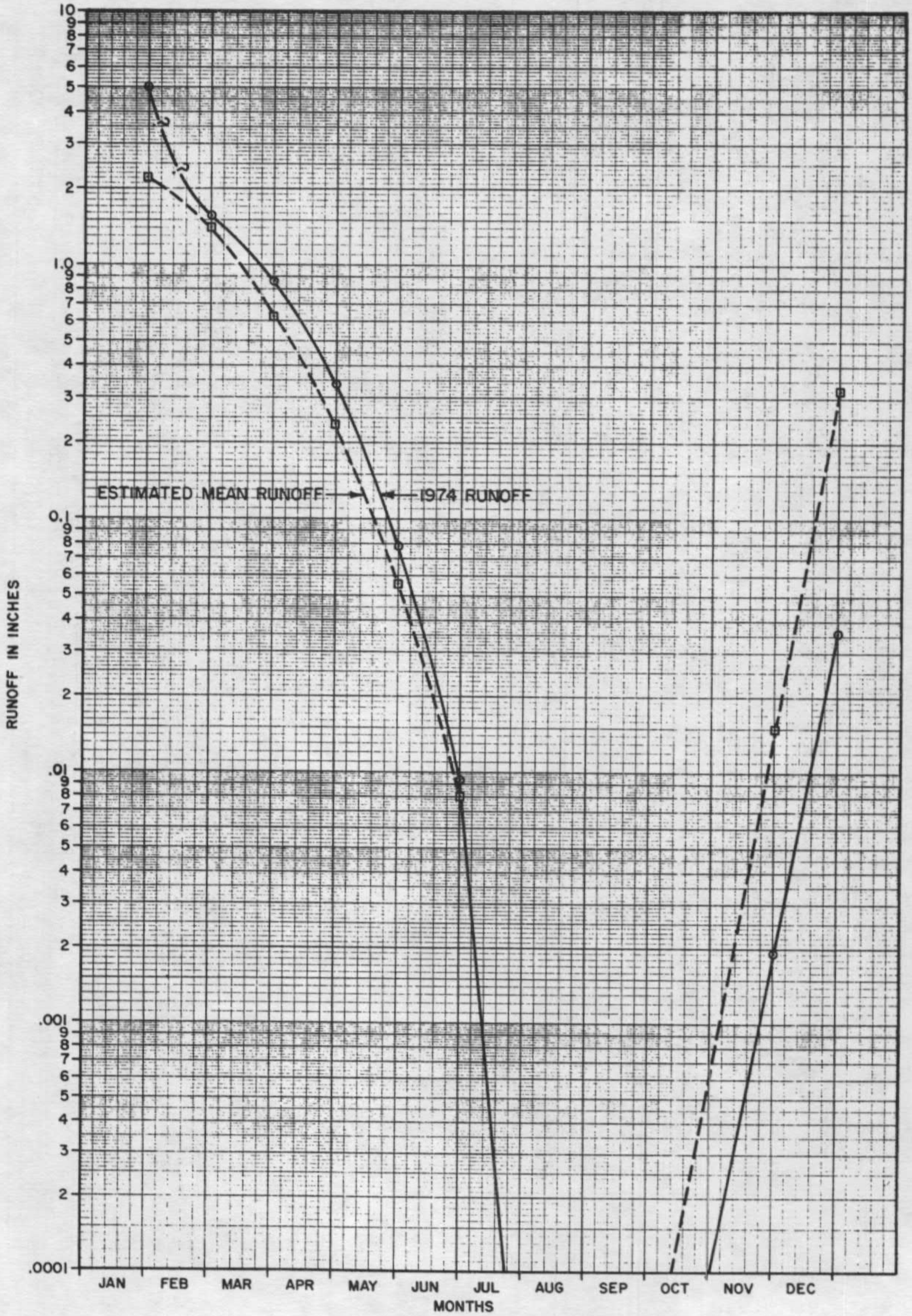
ORCAS RI


ESTIMATED
MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

ORCAS R2

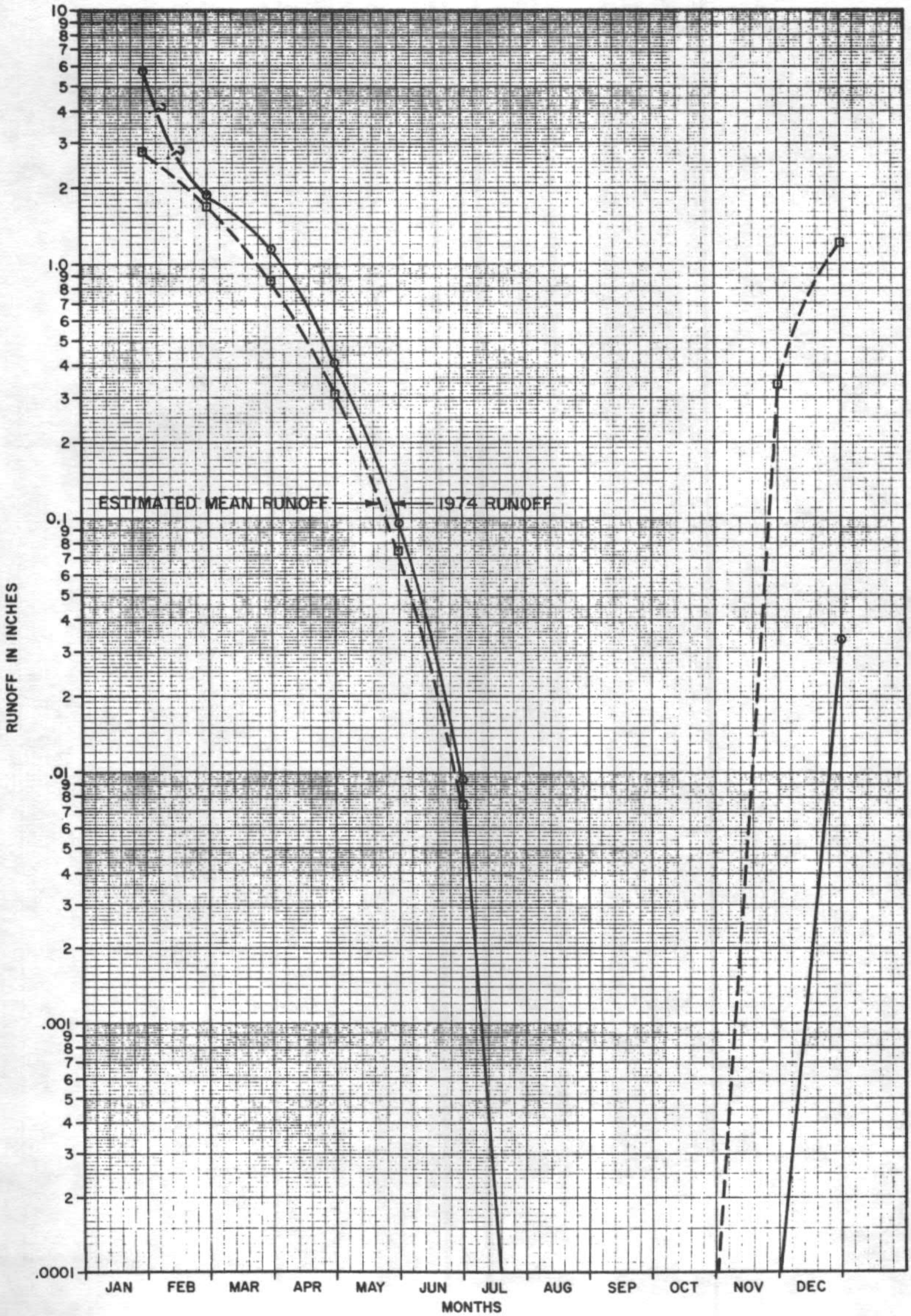

RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN I



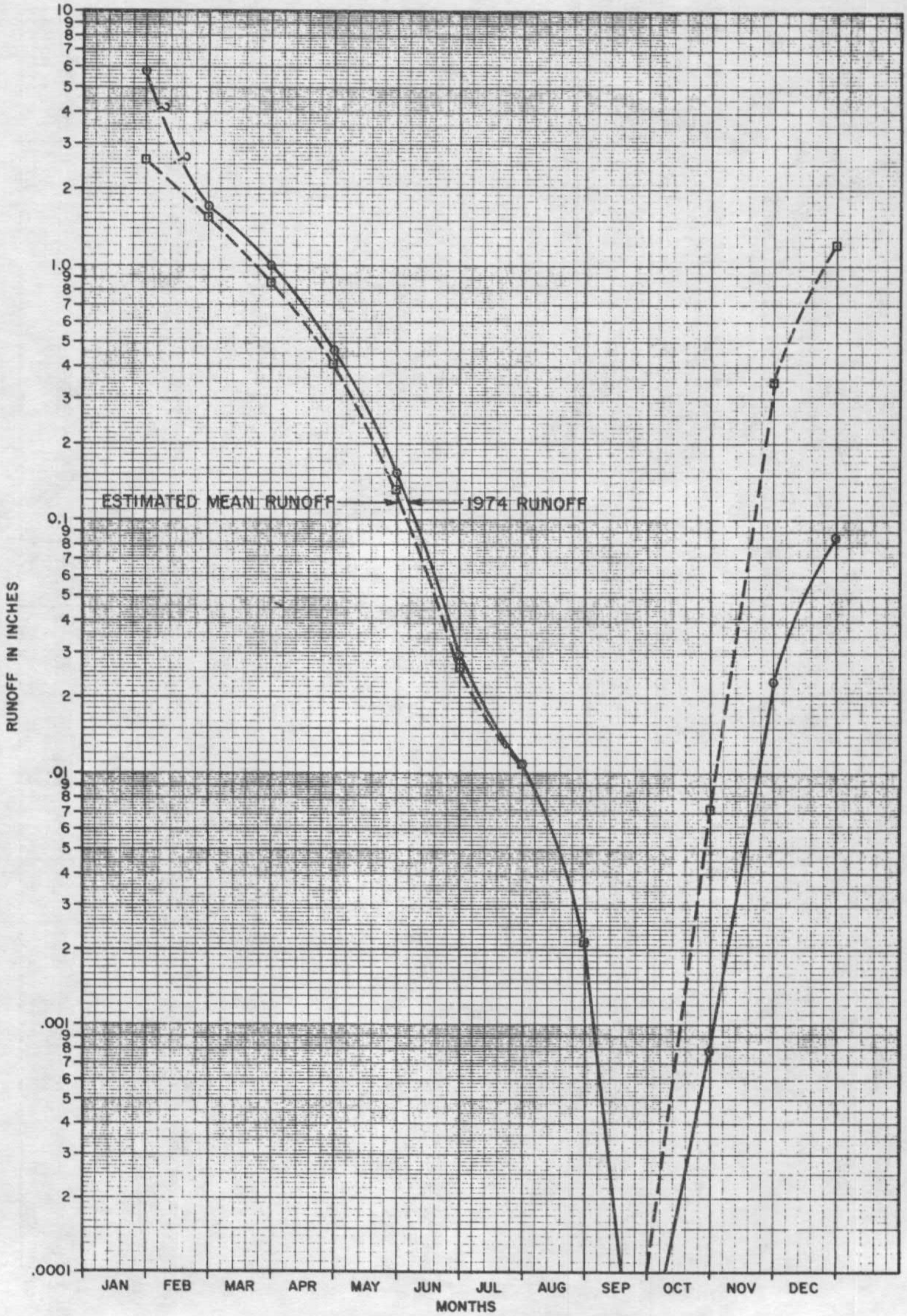
ESTIMATED MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 4



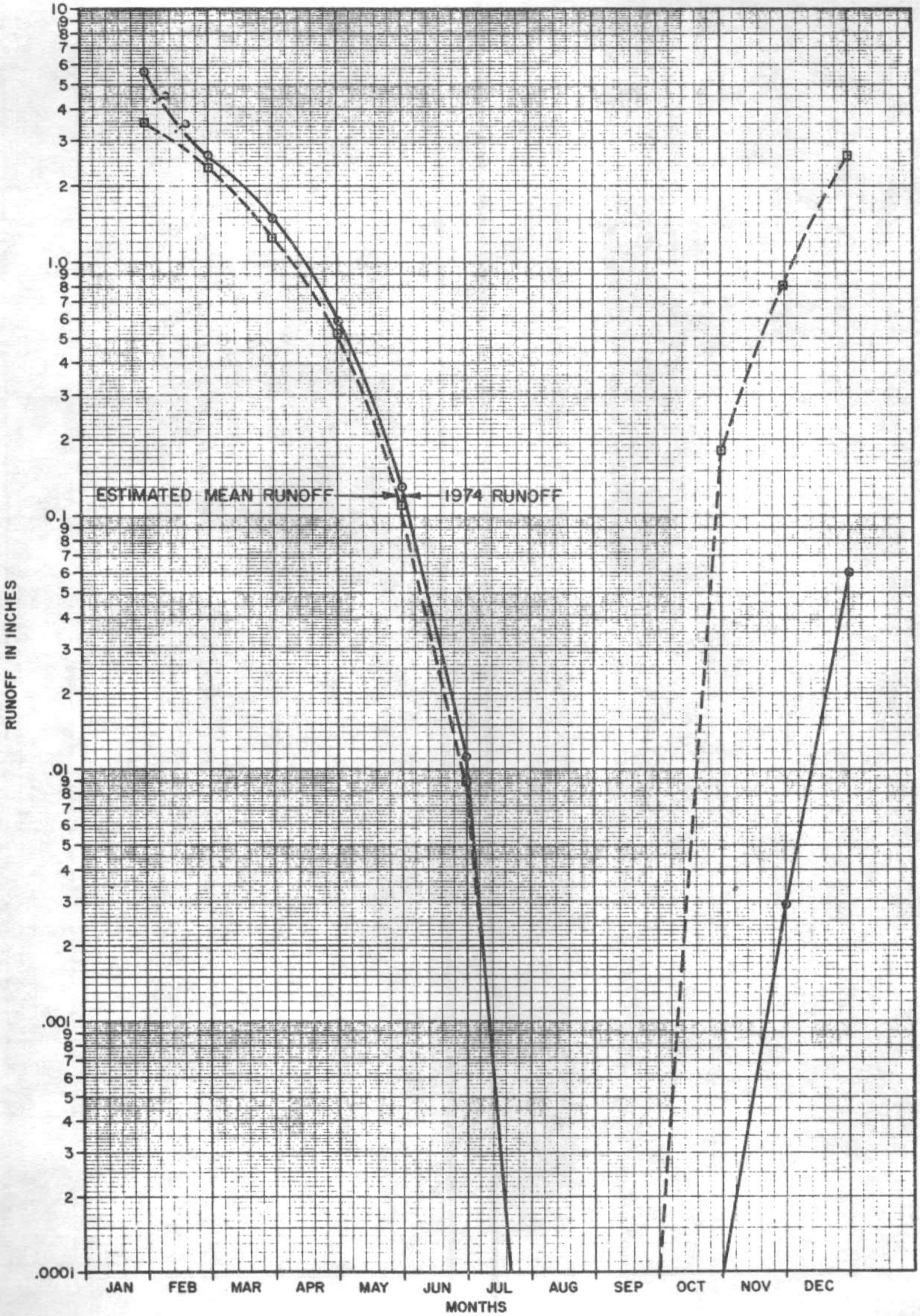
ESTIMATED MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 5

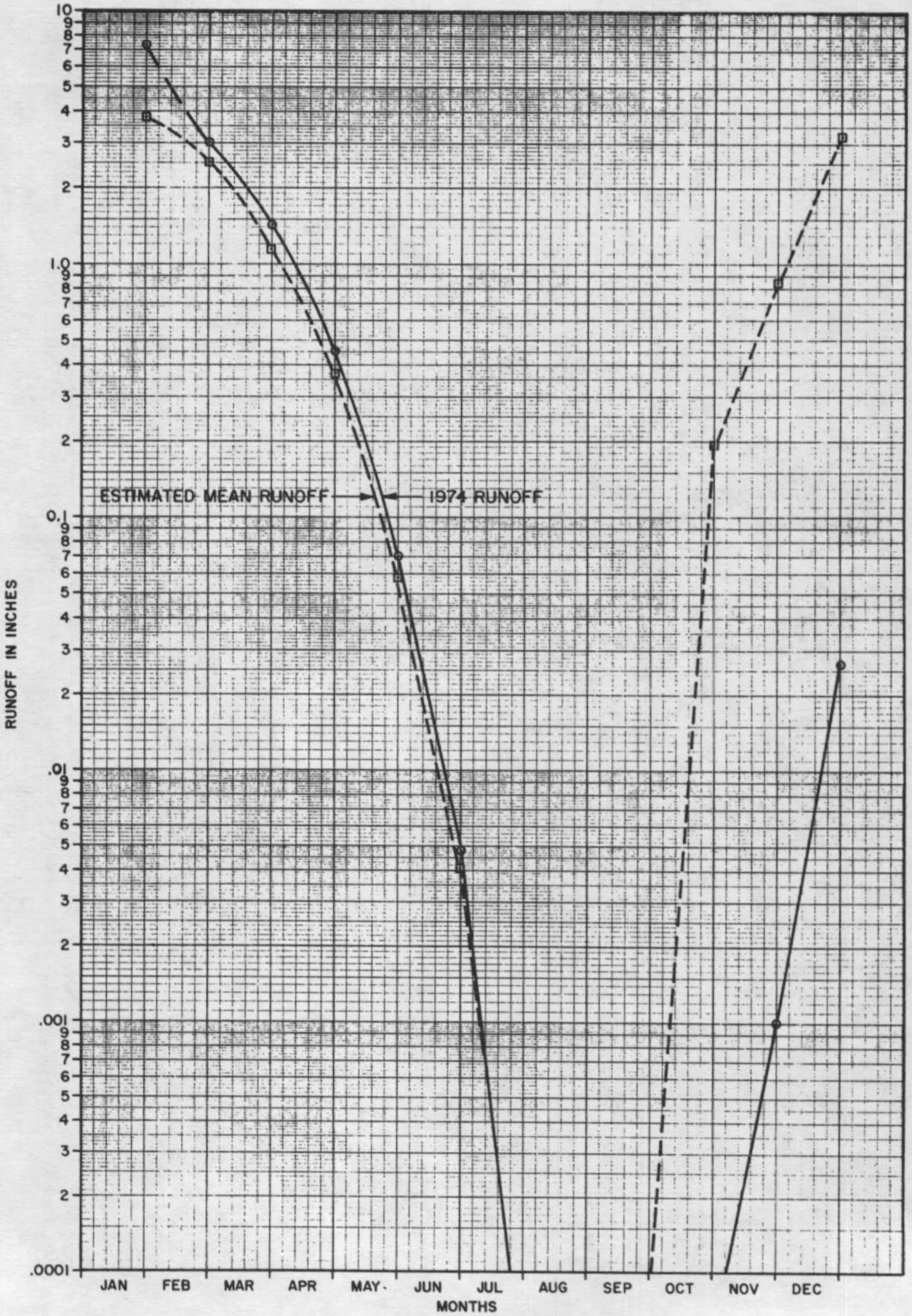


RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 6

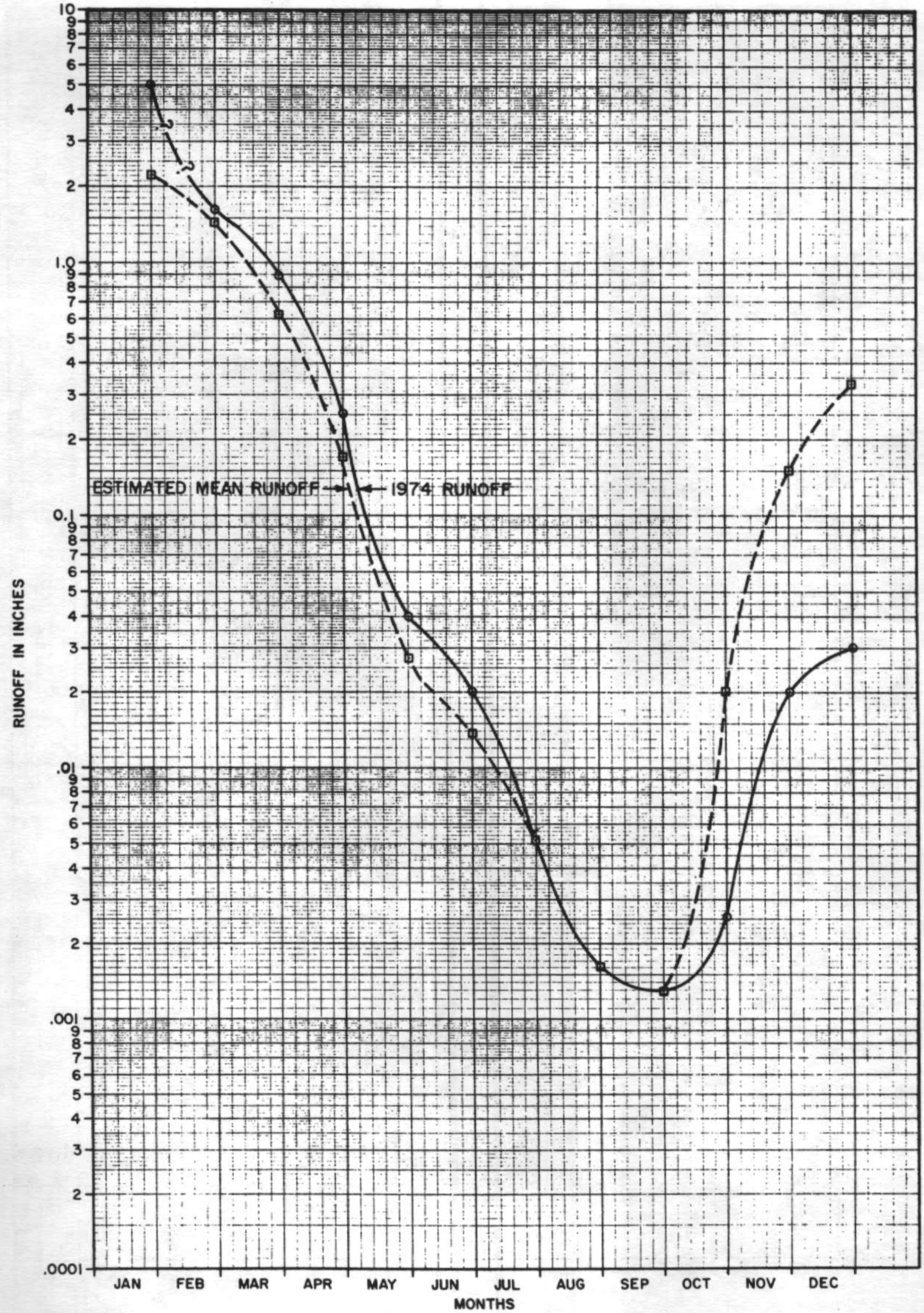

RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 9

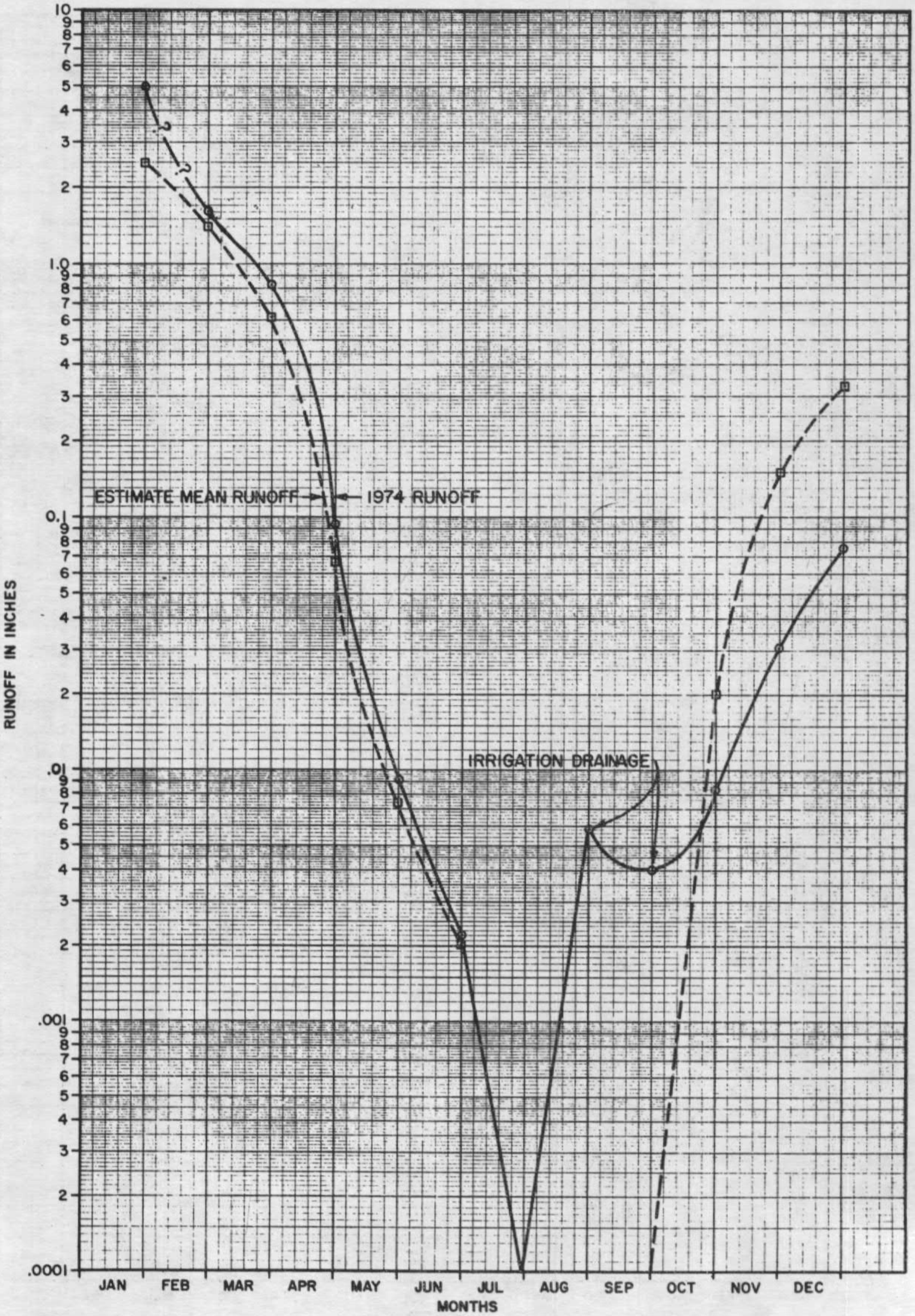


RUNOFF IN INCHES
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

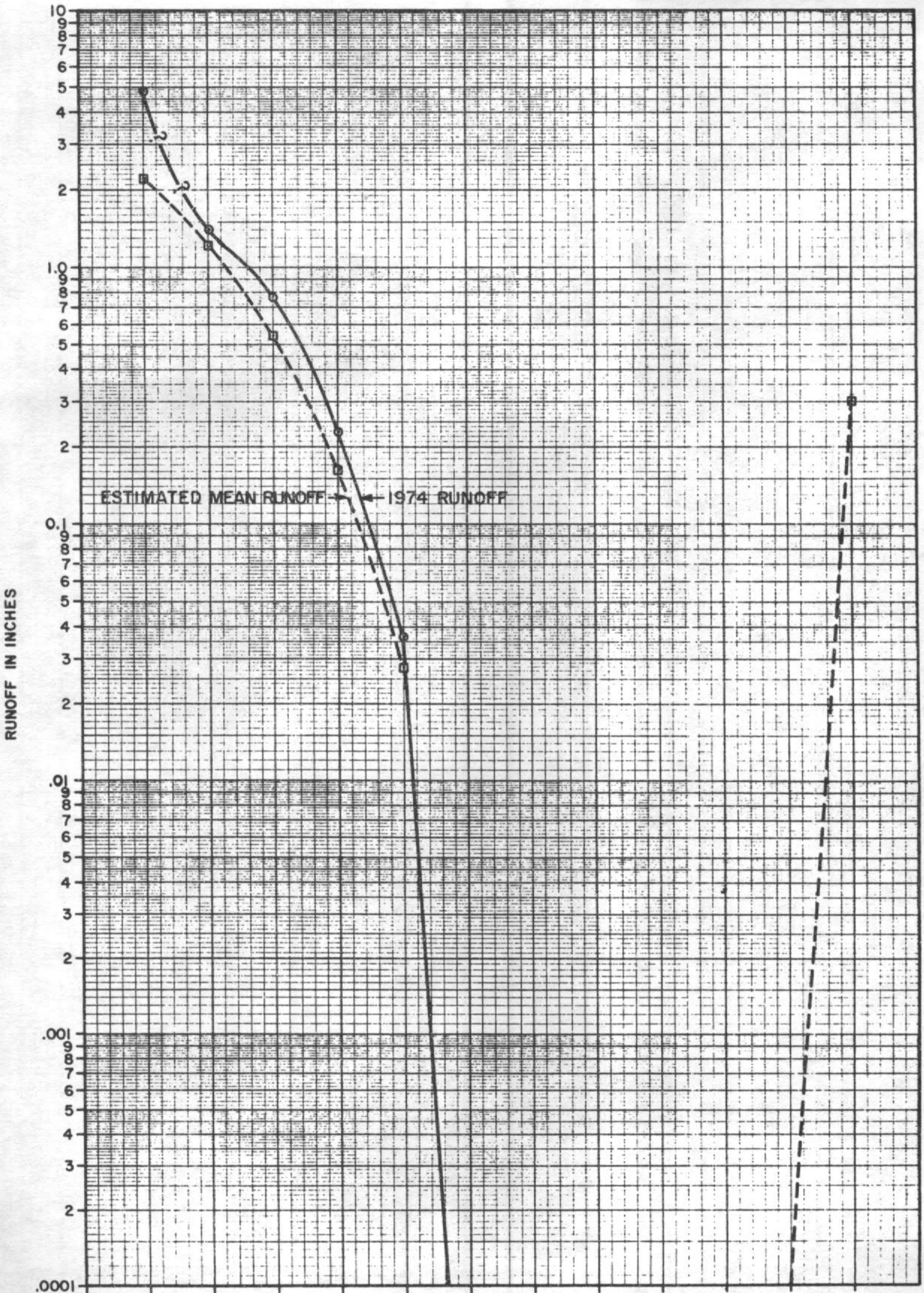
SAN JUAN 10


RUNOFF IN INCHES
10
9
8
7
6
5
4
3
2
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

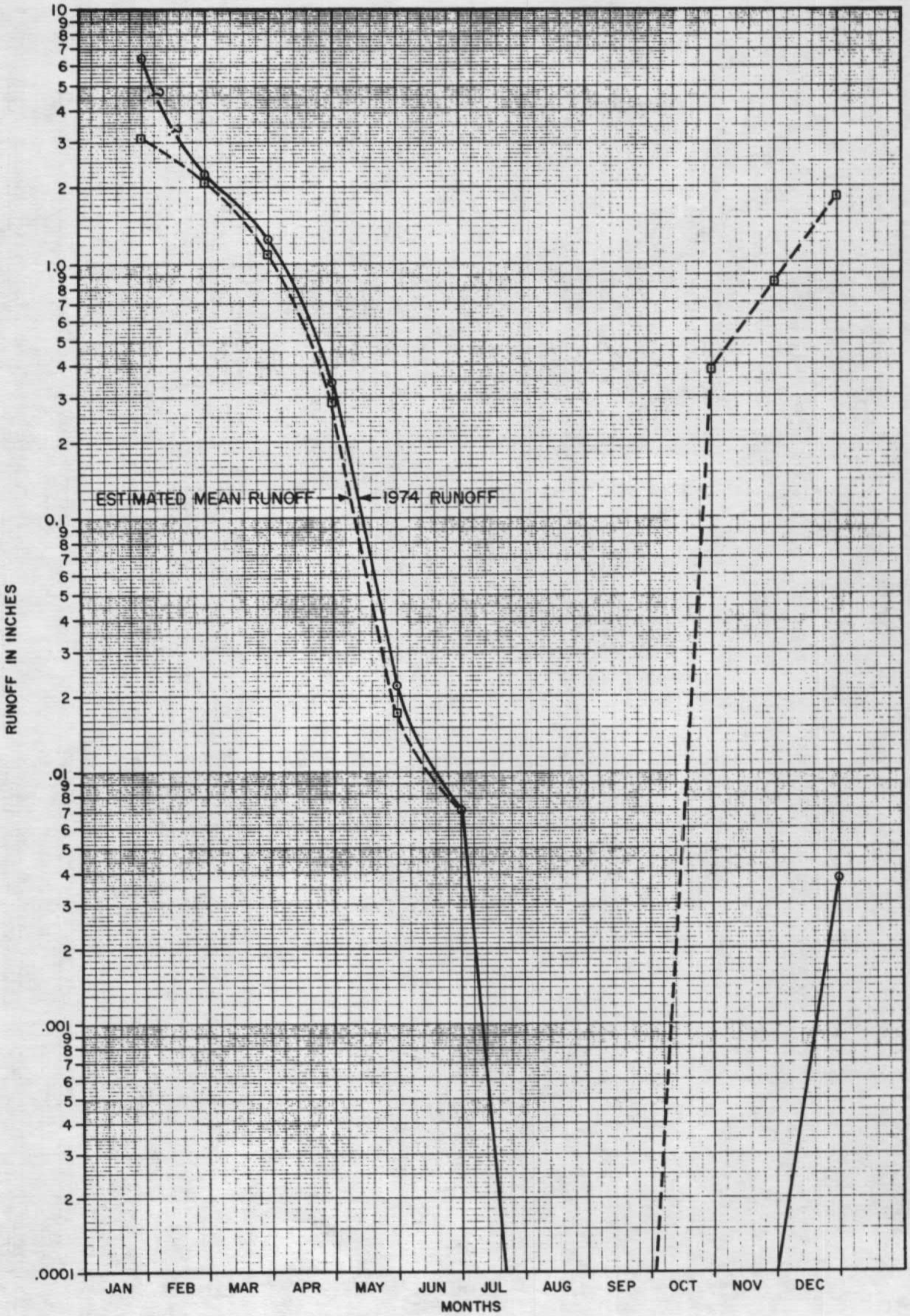
SAN JUAN IIA


ESTIMATE MEAN RUNOFF
1974 RUNOFF
IRRIGATION DRAINAGE
RUNOFF IN INCHES
10
9
8
7
6
5
4
3
2
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 12

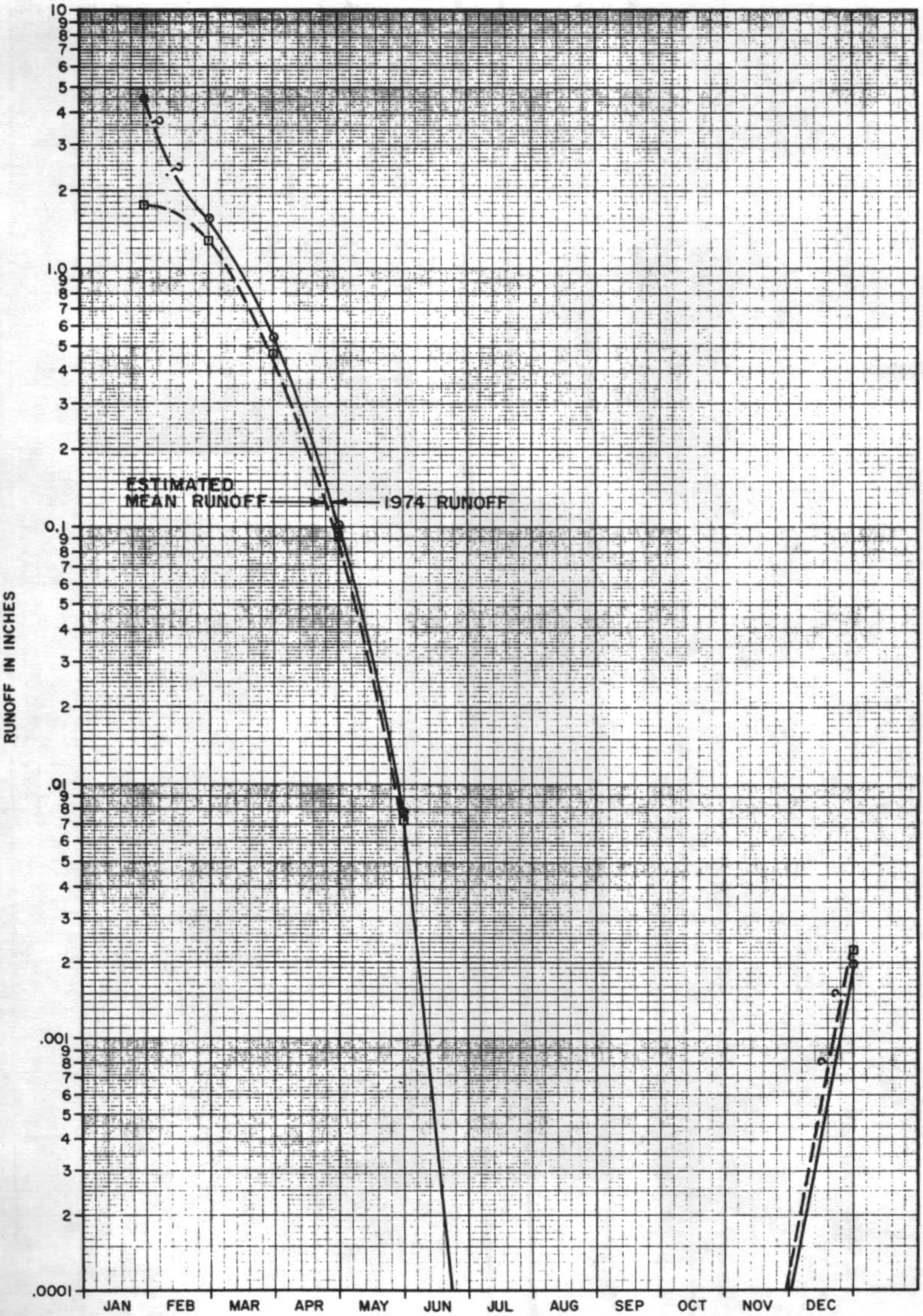

RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 13



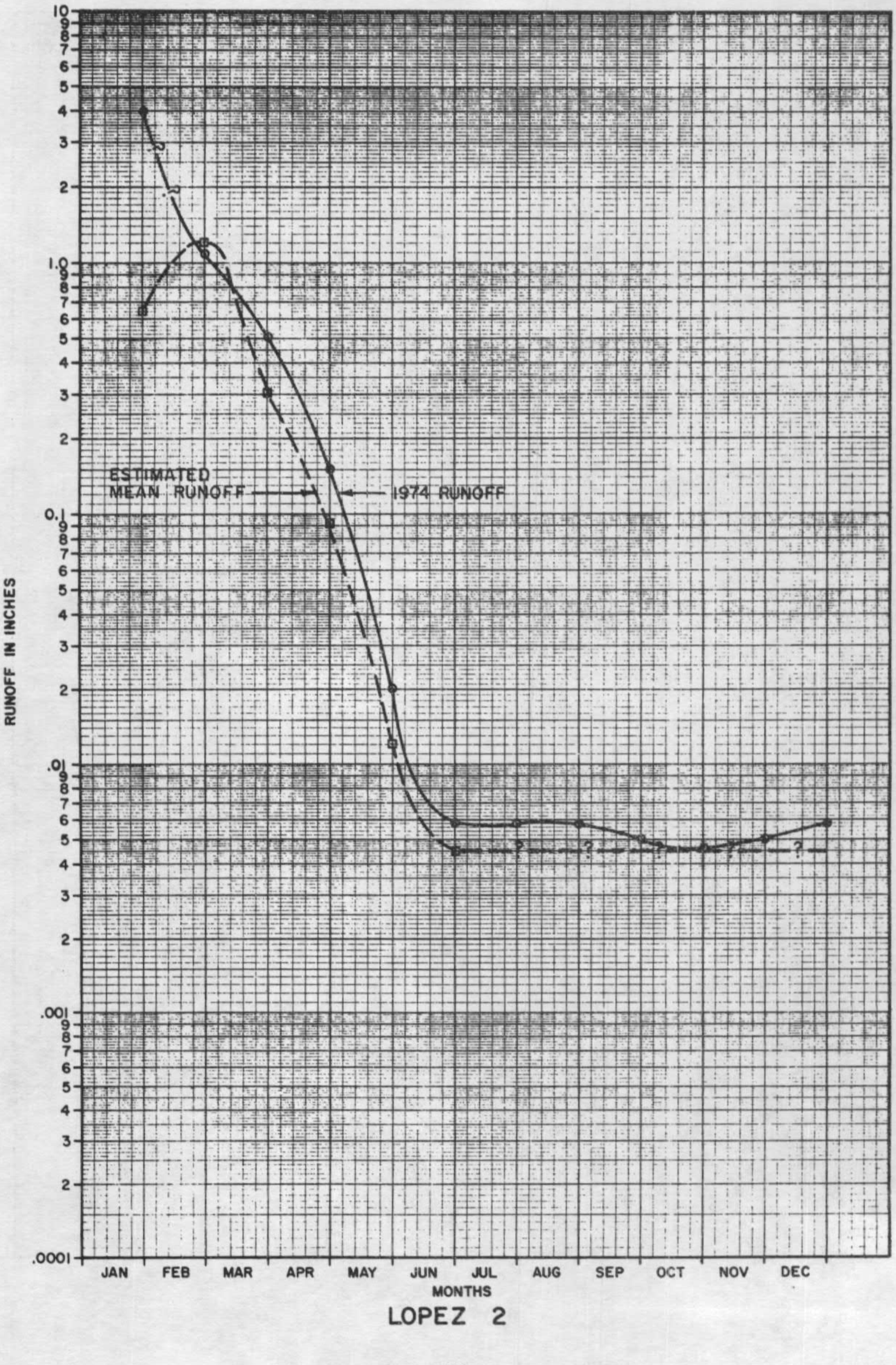
RUNOFF IN INCHES
10
1.0
0.1
.01
.001
.0001
ESTIMATED MEAN RUNOFF
1974 RUNOFF
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

SAN JUAN 14



ESTIMATED MEAN RUNOFF
1974 RUNOFF
RUNOFF IN INCHES
MONTHS
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

LOPEZ I



RUNOFF IN INCHES
ESTIMATED
MEAN RUNOFF
1974 RUNOFF
10
1.0
0.1
.01
.001
.0001
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHS

LOPEZ 2

APPENDIX E

A Method to Predict Mean Annual Precipitation And Runoff in a Watershed

This technique can be used for each month in which there is surplus water. The average is then taken of all the monthly values to get a best estimate.

The results of this analysis can be plotted on a map and contour lines of equal precipitation can be fitted to the data. An isohyetal map of precipitation can then be made (Figure 1) using these data and the contour method. Using the Thornthwaite-Mather method to estimate water loss to evapotranspiration, a runoff map (Figure 12) can be made from the precipitation or isohyetal map. This technique assumes that there is little net change in ground-water storage with time and, therefore, does not incorporate ground-water depletion and recharge in the calculations. It assumes that the rainfall distribution pattern at the weather station is representative of rainfall distribution in distant watersheds with different mean elevations. It also assumes that the estimated runoff is from precipitation in the month measured rather than in the previous month. In other words, there is no significant delay in runoff from precipitation. The latter two assumptions probably cause great errors in the estimated average annual precipitation, yet usually the measured runoff for February and March would predict remarkably similar estimates for mean annual precipitation. These predictions were in all cases in agreement with weather station data (official and unofficial—Figure 1) and the regional pattern of rainfall, and could be plotted against mean elevation with modest scatter to give a reasonable estimation of change of precipitation with elevation (Figure 6). Therefore, although this technique requires somewhat unreasonable assumptions, it produces very reasonable results.

Description of Technique

Available data:

1. Estimated average monthly runoff in cubic feet per second for each month for each watershed for 1974 (page).
2. Estimated monthly evapotranspiration from the Thornthwaite-Mather method (Figure 9).
3. Monthly average precipitation from 83 years of record at weather station (Figure 5).
4. Monthly precipitation for 1974 at weather station.

Technique:

1. Convert mean monthly discharge (cfs) to inches per month of runoff using equation (1).

$$\frac{\textit{cfs x days in the month}}{\text{area of watershed (sq. mi.)}} \times 0.03719 = \text{inches per month of runoff} \quad (1)$$

2. Calculate ratio of 1974 monthly rainfall to average monthly rainfall for 83 year record.
3. Calculate percent of annual rainfall which falls in each month in an average year.
4. Use the following formula to determine average annual precipitation (P) in each watershed.

$$\underset{\text{(inches)}}{P} = \frac{(\text{R.O.} + \text{AET})}{R_1 \ R_2} \quad (2)$$

where R.O. = estimated runoff for month (inches for 1974)

AET = estimated monthly evapotranspiration (inches)

R_1 = 1974 month precipitation at weather station divided by average annual precipitation at weather station.

R_2 = average monthly precipitation at weather station divided by average annual precipitation at weather station.

Example:

at SJ-1 in February

R.O. = 2.57 inches
PET = AE = .95 inches
R_1 = 3.27/2.95 = 1.11
R_2 = 2.95/29.22 = .101

$$\text{then } P = \frac{(2.57 + .95)}{(.101)(1.11)} = 31.40 \text{ inches}$$

PART V

Quality of Waters of San Juan County

By Michael S. Tomlinson

ABSTRACT

Surface water quality in the San Juan Islands may be classified as fair to poor with few exceptions. For the most part, this is due to low flow conditions, ponding of water, and human activities. There are few similarities between surface waters and ground waters. Not only are concentrations of ions greater in ground water, which might be expected, but the ion ratios are different. Except for the hardness of the water, most ground water is of good quality. The ground water quality is essentially a function of the geology of the aquifer from which the water comes. No trends are readily seen between wells on the islands due to an extremely varied geology and an insufficient number of sampled wells. Both ground and surface waters will be affected by the continuing activities of man. Continued pumping of wells may invite sea water intrusion and improper disposal of sewage will further contaminate surface waters and some shallow wells. Farming activities, if improperly managed, will continue to add nutrients to surface water causing advanced eutrophication in surface water. In an effort to check these ever increasing problems, continuous monitoring of water quality and good management of both water use and possible contaminating activities is recommended.

WATER QUALITY STANDARDS

As a means of gaging water quality in terms of acceptability, the water of the San Juans, both ground and surface, was compared with the Washington State Board of Health Regulations for *Drinking* Water (WAC 248-54-430) as of March, 1973. Some changes in these regulations are expected in the fall of 1974; however, the 1973 regulations still make a convenient yardstick.

While in many instances too little water was collected for bacteriological samples to be statistically sound, they do indicate the need for further investigation. According to the Regulations: "When the membrane filter technique is used, the arithmetic mean coliform density of all standards samples examined *per month* shall not exceed one per 100 ml. Coliform colonies *per standard* sample shall not exceed 3/50 ml., 4/100 ml., 7/200 ml., or 13/500 ml. in two consecutive samples."

The following table gives the maximum acceptable concentrations of specific chemical constituents in public drinking water:

Table: 1.

Substance	Concentration mg/liter
Chloride (Cl)	250.0
Iron (Fe)	0.3
Nitrogen (N) (nitrate plus nitrite)	10.0
Zinc (Zn)	5.0

While requirements for hardness limits of water vary with use, the Durfor and Becker (1964, p. 27) descriptive classification is acceptable when characterizing waters for domestic use. The system is described as follows: 0-60 ppm/soft, 61-120 ppm/moderately hard, 121-180 ppm/hard, and more than 180 ppm/very hard. These concentrations affect the soap or detergent requirements in the home, cleaning ability of the water, etc.; however, they are no threat to human welfare, merely a nuisance.

ANALYTICAL METHODS

The constituents and properties of the waters sampled are shown in Table 2 (surface water) and Table 3 (ground water). Chemical constituents, total hardness, and dissolved oxygen (also in % saturation) are reported as parts per million (ppm). Specific conductivity is reported in micromhos per centimeter at twenty-five degrees celsius (umhos/cm @ 25°C). All bacteria values are reported as counts per one-hundred milliliters of sample (#/100 ml). Miscellaneous values such as stream flow are in cubic feet per second (cfs), temperature as degrees celsius (°C), and depth in feet. Note also the use of such symbols as "greater than" (>), "less than" (<), and estimated (E).

Stream flows, measured with a Price "Pygmy" meter, and well levels were both measured according to U.S. Geological Survey (USGS) standards. In flow measurements, stream beds were occasionally modified to an ideal channel (i.e. no obstructions) to produce a less turbulent, more constant flow in a section across the stream.

Temperature was determined with a mercury thermometer to the nearest one-tenth degree celsius. All but the April pH values were determined in the field with an

Analytical Measurements pH Meter, Model 107, and read to the nearest one-tenth unit. Conductivity in all instances was determined using a conductivity bridge, (different makes vary). February samples were analyzed by the U.S.G.S. Central Laboratory at Salt Lake City, Utah. All other samples were analyzed by the Water Quality Laboratory of the Department of Ecology. Hereafter any differences in analytical methods are noted.

Calcium, magnesium, and sodium were determined by both agencies using a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer from unfiltered samples. Hardness, reported as $CaCO_3$, was calculated using the concentrations of calcium and magnesium in ppm multiplied by the factors 2.497 and 4.116 respectively and totaled according to Standard Methods, 13th Edition.

Total zinc and iron in the April and August samples were determined by the Department of Ecology with the Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer. The total zinc in February's samples done by U.S.G.S. were determined on the Model 403. Total iron values determined by U.S.G.S. were done with the bipyridine method utilizing an Auto Analyzer II.

Both agencies used the potentiometric method of determining alkalinity, thereby calculating the bicarbonate ion according to Standard Methods, 13th Edition. Chlorides were measured by the Department of Ecology using Standard Methods' mercuric nitrate titration method, while those determined by U.S.G.S. were made using the mercuric thiocyanate method in conjunction with an Auto Analyzer II.

The nutrients, nitrates and total phosphates were analyzed by both agencies using an Auto Analyzer II according to a modified Standard Methods procedure. The nitrate method utilizes cadmium reduction while total phosphates were determined by the ammonium molybdate-ascorbic acid method. Dissolved oxygen values were obtained in the field using a modified Winkler titration method and reported to the nearest one-tenth ppm. Percent oxygen saturations were calculated with a table which considers the theoretical oxygen concentration at a given temperature.

Bacteria concentrations were determined by both U.S.G.S. and Department of Ecology using the membrane filter technique as described in Standard Methods.

SURFACE WATER QUALITY

Twenty-one surface water sites, located on six streams and 10 lakes or ponds on Orcas, San Juan and Lopez Islands (Figure), were sampled in the course of three months (February, April and August, 1974). Of the twenty-one sites, only four (see repeats, Table 2) were sampled a second time due to low or zero flow conditions which exist during the summer months in the San Juan Islands.

The surface waters of the San Juan Islands have been technically classified as Class A (excellent) according to Revised Water Quality Standards established by the Department of Ecology. Water classified as A is characteristically used for water supply, wildlife habitat, livestock watering, recreation and fish reproduction. Much of the water in the San Juan Islands is below this class due to either natural or manmade causes.

GENERAL CHEMICAL CHARACTERISTICS

The hardness of water can be attributed to the calcium and magnesium ion concentrations. Surface waters on the San Juan Islands may be generally characterized as calcium-magnesium bicarbonate waters (i.e. calcium, magnesium, and bicarbonate ions predominate). Reported as $CaCO_3$, the concentrations range from 25 to 150 ppm which is classified as soft to hard waters respectively.

Much of the surface water on the islands is discolored. It is not unusual to find coffee colored water with foam forming near small rapids. Usually this can be attributed to natural causes, such as the type of soil through which the stream flows. This is mainly an aesthetic problem.

SPECIFIC CONSTITUENTS AND PROPERTIES: THEIR SIGNIFICANCE

Flow

While water quantity is covered in much greater detail in another portion of this report, flow should be considered briefly as it has decided effects on water quality. A common effect seen with decreasing flow is an increase in chemical concentrations. Further increases result with increasing evaporation.

Throughout the San Juan Islands stream flows vary from moderately high (< 20 cfs- to mere trickles or no flow conditions. There are occasional exceptions to this, however, most notable are Key Springs and Cascade Creek on Orcas Island which maintain a relatively constant flow all year. The extreme seasonal variations are the rule however.

Temperature

Water temperatures in the San Juan Islands vary from winter time values of 4°C to summer highs of 21°C. The higher values are usually found in ponds and lakes, especially in summer when many streams are not flowing through the ponds. These higher temperatures have the affect of lowering the amount of dissolved oxygen thus producing a less than ideal environment for aquatic animal life. If excess nutrients are coupled with high temperatures, algal blooms may result which further deplete the dissolved oxygen. In addition to producing harmful environments for fish, these conditions may also accelerate eutrophication. Natural lakes, such as Sportsman's and Hummel, exhibit these phenomena as well as numerous farm ponds formed by the damming of streams.

The most probable cause of nitrates are both human and animal wastes. Due to the geological condition of the San Juan Islands, septic tanks and their respective drain fields function less than ideally. Most of the streams flow through farmland in which livestock are pastured, and pick up substantial amounts of nitrates. These same farmlands further compound the matter by ponding water, allowing it to warm and make an ideal environment for algal blooms. Some of the nitrates may be picked up from the soils. This may be particularly true of a type called Semiahmoo Muck, a peat-like substance. The high value of 3.60 ppm for Beaverton Valley Creek on San Juan Island may be explained this way as it not only flows through farmland, but also it flows almost entirely through this muck. Both nitrates and phosphates may be added through runoff of fertilized farmlands as well, but this possibility requires further investigation. The most probable source for phosphates is household detergents. These detergents may enter the water any number of ways, thus triggering a bloom.

Dissolved Oxygen and Oxygen Saturation

Dissolved oxygen is a convenient method of determining whether water may or may not be suitable for aquatic animals, most importantly, fish. Generally, the lower the temperature, the greater the amount of dissolved oxygen. Wind blowing against a water surface can be a very effective means of adding oxygen to water as well as promoting circulation of other constituents in lakes and ponds. Aquatic plant populations also affect the amount of oxygen in water. During the day, these plants may produce large amounts of oxygen; so much so, that oxygen is given off to the atmosphere as well as supersaturating the water. At night their respiration depletes the oxygen.

Saturation levels in the San Juans range from 0% (0.00 ppm) to 112% (12.3 ppm). The Orcas dump leachate had the value of 0% saturation due to a chemical oxygen demand of 1500 ppm. This is not particularly surprising considering the nature of the material exuding from the solid waste dump. Low values (<70%) were common in the small farm ponds during the summer. One can assume that plant respiration and higher temperatures were the major factor for depletion. For fish, the water becomes lethal at oxygen concentrations below approximately 4.0 ppm. Note that this is regardless of saturation which is relative to temperature (i.e. fish are only interested in absolutes). Several ponds on Orcas Island and one on San Juan Island (AUG 17) where a fish kill occurred fell slightly above or below 4.0 ppm.

Many of the lakes in the San Juans show high saturations and usually high concentration levels for oxygen. First of all, these bodies of water are subject to more wind action and secondly, in most cases, the algal bloom isn't as extensive as it is in the ponds. This is true of those rare streams which continue to run in the summer also. Here, low temperatures and constant aeration facilitate the solution of oxygen as well.

Bacteria

Bacteria in water is useful as a method for determining sources of pollution. There were insufficient numbers of fecal coliform and fecal strep to differentiate human from animal sources by the ratio of fecal coliform to fecal strep (>4 indicates human sources); however, examination of both of these bacteria types plus total coliform indicates that contamination does occur. The most logical sources for this contamination are farm yards and septic tanks. Values for total coliform in surface waters ranged from an estimated 15/100 ml. to 4000/100 ml. with a mean value of approximately 1100/100 ml. As long as this water is not used untreated for drinking water, it is acceptable.

SUMMARY AND FUTURE SURFACE-WATER QUALITY PROBLEMS

Surface water quality ranged from fair to poor, with fairly high dissolved solids, nutrients, and bacteria values. Some of this can be attributed to natural causes. Perhaps predominant are the low flow conditions which exist throughout the Islands. This compounded with the types of soils through which the water flows already produce less than ideal water. Further degradation occurs to the already mineralized, often discolored waters, by human activities. One of the more serious problems is the result of the damming of streams. This slows the flow of water allowing it to warm, which, with nutrients acquired from farms and residences upstream, becomes an ideal environment for algal growth and creates a hostile environment for fish. Upon decomposition of organic material, high nutrient "slugs" are released to the water courses. These farm activities and residences also contribute bacteria to the system which further degrades the water quality.

pH

The pH values of the San Juan surface waters are for the most part between 7.0 and 8.0, which are quite acceptable. Values above 8.0 can, in the San Juans, be attributed during daytime to photosynthesis. One would expect high pH values in lakes with high aquatic plant populations as exemplified by Hummel Lake.

Calcium, Magnesium and Hardness of Water

As stated before, hardness can be attributed to the presence of calcium and magnesium ions. The calcium concentration ranged from 3.8 to 44 ppm with an average of 26.3 and magnesium range of 2.6 to 13.0 ppm with an average value of 6.3 ppm. These ions are most commonly derived from limestone (calcium carbonate) and/or dolomitic limestone (calcium-magnesium carbonate) which are present on some of the islands. If these deposits are surficial, the streams may pick them up by direct solution; otherwise the minerals may be dissolved by ground water which then enters a surface water body. Little is known at present about reasons for existing distributions and the seasonal variations of these ions.

Sodium

Sodium values for surface waters ranged from 4.6 ppm - 75 ppm with a mean value of 17.9 ppm. The highest sodium value was 75 ppm found in a small pond on San

Juan Island (AUG 17). The high sodium values of this pond may be attributed to the mass degradation of organic matter. Higher sodium values appear to be associated with numerous ponds as well as some smaller lakes such as Hummel and Sportsman's. In all of these, substantial algal blooms are evident leading one to believe that the major source of sodium in these waters is organic decomposition. Soils and assorted rock types may also contribute to the sodium concentration but to a lesser degree.

Iron

The presence of iron in drinking water is considered a nuisance. Not only do low concentrations of iron impart an unpleasant taste, but such domestic duties as clothes laundering are seriously hampered by iron which may produce a rust coloring. A maximum concentration of 0.3 ppm is acceptable for drinking water according to the Washington State Board of Health Regulations.

The San Juan Islands iron concentrations ranged from less than 0.1 to 1.7 ppm. The high value was due to degradation of organic material in the farm pond (AUG 17) mentioned previously. Those surface waters analyzed for iron show that approximately one-half are above the suggested maximum of 0.3 ppm, but as most of these surface waters are not utilized for human consumption, these values are of no great consequence. The most probable sources of this iron are either from groundwater which has picked up iron through the material it contacts or as one of the products of organic decomposition. For surface waters, organic decomposition is perhaps the most dominant source. This is admirably evidenced by the above mentioned pond and also by the fact that the higher iron values of approximately 0.8 ppm are found in ponds with large aquatic plant populations and little or no flow-through of water. Here, not only does decomposition add iron to the system, but evaporation increases the concentrations.

Bicarbonate and Chloride Ions

The most common source of bicarbonates may very well be from carbon dioxide gas as either absorbed by the water from the air or by photosynthesis. Another source is solution of carbonate rocks, which, as mentioned earlier, would not only add bicarbonate ion, but calcium and magnesium ions as well.

The bicarbonate concentrations range from 20 to 160 ppm with a mean concentration of 78 ppm. Concentrations greater than 78 ppm were either from mineralized waters such as Key Springs on Orcas Island or from fertile little farm ponds scattered about the Islands.

The average chloride ion concentration of 9.5 ppm and for that matter, the maximum of 120 ppm, are far below the Health Regulation maximum limit of 250 ppm. These values show very little in common with the ground water of the San Juan Islands. One possible reason is a difference in sources. Possible sources for the surface water chlorides are the material through which the water flows and in the case of Station APR14 (120 ppm), leachate from a solid waste dump on Orcas Island. It might be noted that while this value is below the maximum limit, this water was, when viewed as a whole, anything but above standard.

Nitrates and Phosphates

Nitrate values range from 0.00 to 3.60 ppm. While low according to Health Regulations, they are still significant when considering suitabilityy for algal growth. All that is needed to start a rather extensive bloom are the necessary phosphates, which is probably the limiting nutrient. With a range of 0.02 to 0.54 ppm for phosphates, there are sufficient nutrients and in a pond environment with warm water, blooms do occur. This can be seen in numerous ponds and lakes in the Islands. It is noted that the nitrate values drop to zero in some of these waters which indicates that the algae has taken up all available nitrate, halting further population growth and thus stopping the uptake of further phosphates. Given the time and conditions, this plant life may die, release the nutrients and a second bloom may occur. These extensive blooms deprive aquatic animal life of needed oxygen, thus causing death and further deterioration of water quality.

Not all impounded water in the San Juan Islands is of poor quality. Trout Lake, a reservoir for the town of Friday Harbor on San Juan Island, has exceptionally good quality water. The principal reason is that this lake lies outside the influence of man and is in a protected watershed. Key Springs on Orcas Island, though they have hard water, are of good quality and relatively constant flow. Mountain Lake also has good quality water and here again, it is principally because it is remote from the influence of man. Here one sees a trend that is not too surprising. The more a stream is exposed to the activities of man such as farming, sewage disposal, solid waste disposal, development of ponds, etc., the worse its water quality becomes.

A few predictions can be made as to future problems concerning water quality. The continued damming of streams to produce ponds will lead to a string of marshy areas with very poor water quality. The continuation of population growth without proper sewage disposal will add more nutrients to streams which, when ponded or when entering a lake, will accelerate eutrophication. This is also true of farming if techniques remain the same. As the population increases, even if only in summer, the chances for contamination exist.

Little can be done about the natural causes for water quality degradation; however, careful management of present and future uses of water and the surrounding land may halt further degradation. The possibility exists that water quality may improve if the land owner realizes that the pond he owns or proposes to build will almost invariably be choked with weeds and may be unsuitable for fish. Also his septic tanks may have to be abandoned for a sewage system capable of handling sporadic and increasing loads. Solid waste disposal facilities will have to consider the geology and hydrology of the area so as not to contaminate the water. And lastly, farms will have to carefully control and apply fertilizers as well as move livestock further from the water even if it involves pumping the water to the livestock. While these measures are restrictive and perhaps harsh, there is the possibility of improving surface water quality. In an effort to determine this, it might be advisable to monitor the surface waters of the San Juan Islands on a quarterly basis.

GROUND WATER QUALITY

Of the twenty-four wells sampled in San Juan County, seven were on Lopez Island, eight on Orcas Island, and nine on San Juan Island. Six of these wells were sampled several months later in an attempt to determine if any temporal variation occurs. For the most part, any variations that did occur could be attributed to analytical error (approximately 10%). One well, designated APR02, is excluded in considerations of water quality because of its unusual characteristics due to salt water contamination by a gravel washing operation. The reader is once again urged to consider the geologic map of the San Juan Islands in all of its complexities when covering this section on ground-water quality as geology is definitely an important factor.

GENERAL CHEMICAL CHARACTERISTICS

The groundwater of the San Juan Islands is exceedingly varied, largely due to the diversity of numerous, separate aquifers. These variables are examined more closely in the section concerning specific constituents because constituent concentrations are frequently reflections of varying geology. The groundwater may be characterized as calcium-magnesium bicarbonate waters, sodium chloride waters, or sodium bicarbonate waters.

Such constituents as dissolved oxygen, nitrates and phosphates are not considered. While the nutrient concentrations are comparable to surface water values, they lack the importance they have in surface waters where they are utilized by plants. These nutrients may be used for indicating contamination but the concentrations are low, thus classing the water in that respect as above standard. Dissolved oxygen also lacks importance in groundwater and the chances of erroneous values are high due to minute air leaks in pumps and lines. A range of 6.2 to 9.5 with an average of 7.3 was found for pH values. The average is quite close to neutral. The higher values were found in the only two wells which may be classified as sodium bicarbonate (HCO_3^-) wells.

Specific conductance is a useful indicator of the degree of mineralization of the water. Conductivity values varied from 117 to 3000 umhos/cm. The lowest values were from Orcas and San Juan wells with Lopez values being substantially higher. Possible reasons for this are covered in the following sections.

SPECIFIC CONSTITUENTS AND PROPERTIES: THEIR SIGNIFICANCE

Calcium, Magnesium and Hardness of Water

The average total water hardness in the San Juan Islands is approximately 205 ppm (very hard) with a range of 1 ppm to 568 ppm. In ground-water, as well as surface water, the most probable source of calcium, magnesium and bicarbonate ions is limestone. The two wells (Orcas, AUG01, and San Juan, AUG20) with the softest water have, instead of calcium and/or magnesium, sodium as the major cation. Also, these wells have higher than average pH values (8.4) as well, which is conducive to the carbonate ion formation. The presence of these two anomalous wells is, as yet, unexplained.

Sodium and Chloride Ions

Sodium values range from 5.8 to 260 ppm with a mean concentration of 93 ppm. Excluding the two anomalies mentioned above, most of the sodium is accompanied by almost equal concentrations of chloride ion (sodium chloride or common table salt). Chloride values range from 6 to 447 ppm. The average value of 87 ppm is well below Health Regulation's limit of 250 ppm; however, several wells on Lopez and San Juan Island either approach or surpass this value. Lopez Island, where wells are developed almost entirely in glacial gravels, reveals the highest average chloride values (134 ppm) as compared to San Juan Island (102 ppm) and Orcas Island (19 ppm) which have complex hard rock geologies.

As salt seems to be the dominant constituent in some of these wells, one can hypothesize as to sources. The salt may be due to old deposits left as this once submerged land rose relatively to sea level. This could be in the form of salt deposits (evaporites) or as trapped ancient sea (connate) water. If this is the case, as the water is used the salt concentration should decrease due to leaching; therefore, no serious problem exists. If salt concentrations increase with time there is the distinct possibility that sea water intrusion is occurring. San Juan Island and particularly Lopez Island are susceptible to sea water intrusion.

Iron

The average iron concentration in groundwater is approximately 0.25 ppm excluding one very high value of 8.0 ppm found in a well near Hummel Lake on Lopez Island. Health Regulations state that 0.3 ppm is the limit for iron in drinking water. Lopez Island seems to have the highest values though the reasons are unknown. As mentioned in the surface water section, iron may originate in the materials through which the water passes and from organic decomposition.

Bacteria

Since a standard 250 milliliters of water was taken for bacteria samples, wells, which normally have zero or low bacteria counts, show statistically non-significant numbers. Should a well show any total coliform, it definitely warrants a closer examination by the County Health Department. The sources of bacterial contamination for wells are the same as for surface waters, in close proximity to barnyards and septic tank drainfields. As previously stated geologic conditions of San Juan County are such that septic tank drainfields do not function particularly well (i.e. insufficient filtration).

SUMMARY AND FUTURE GROUND-WATER QUALITY PROBLEMS

Ideally one should be able to establish some relationship between geology and chemical water quality. At present, however, this is impossible due to the highly varied geologic units of the San Juans. In some areas of the state, it is possible to identify various aquifers from the quality of the water they yield. This requires something not yet accomplished in the San Juans, namely, a sufficient number of wells in a single aquifer to establish certain trends. Should one decide to establish some relationship between geology and water quality, many more wells must be studied.

Examined individually, there are wells affected by the presence of limestone, other minerals, salt water and man. Whereas the first two factors amount to normally no more than a nuisance, the latter two factors may become serious. Man and his activities for the most part contaminate wells with bacteria. The presence of salt water, however, is a more complex and possibly very serious problem. Should the salt water prove to be relict water (left over from ancient times) then the problem is not particularly grave. However, if the salt water is due to sea water intrusion then the problem could become worse and in time the water will become unusable. It is felt intuitively that Lopez Island (most wells) in particular and possibly San Juan Island FEB 17, AUG 12, 13 and 19) are in the first stages of this problem. Unfortunately, at present, it is difficult to prove. It might be wise to monitor the sodium chloride (salt) concentration of the water in several wells over the next few years on a monthly basis. If an increase is detected, sea water intrusion may be confirmed and the appropriate measures taken.

In addition to sea water intrusion, well contamination exists which might increase in the future. A minimum requirement would be the proper sealing of wells. The most effective method would be the proper disposal of sewage (i.e. via an effective sewage treatment plant). Also, in farming areas, one must consider the proximity of barnyards to wells. As in the section on surface waters, continuous monitoring by the county is recommended in an effort to detect changes in quality.

REFERENCES

Durfor, C.N., and Becker, Edith, 1964, Public Water Supplies of the 100 Largest Cities in the U.S., 1962: U.S. Geological Survey Water-Supply Paper 1812.

Hem, John D., 1970, Study and Interpretation of the Chemical Characteristics of Natural Water (2nd Ed.), U.S. Geological Survey Water-Supply Paper 1473.

Hutchinson. G. Evelyn, 1957, A Treatise on Limnology, V. I., John Wiley & Sons Inc., New York, New York.

McLellan, Roy D., 1927, The Geology of the San Juan Islands, University of Washington Press, Seattle, Washington.

Taras, M.J. (Ed.), Greenberg, A.E. (Ed.), Hoak, R.D. (Ed.), and Rand, M.C. (Ed.) 1971, Standard Methods for Water & Wastewater (13th Ed.), American Public Health Assoc., New York, New York.

U.S. Environmental Protection Agency, 1973, Proposed Criteria for Water Quality.

U.S. Soil Conservation Service, 1962, Soil Survey San Juan County, Washington, Series 1957 No. 15.

Washington State Board of Health Regulations for Public Drinking Water, 1973.

Appendix Two

Driller's Logs of Representative Wells of San Juan County

Appendix Two -- Drillers' Logs of Representative Wells

Material	Thickness (feet)	Depth (feet)
34/1W-6C1		
Phillips, Donald; drilled by San Juan Drillers, April 24, 1974		
Till, glacial	7	7
Rock, hard, igneous, gray-green	58	65
34/1W-6F1		
Marcen, Stan; drilled by San Juan Drillers		
Soil	1	1
Till, glacial	9	10
Clay, brown	9	19
Shale	1	20
Rock, igneous, green	43	63
Rock, gray	1	64
Rock, igneous, green	16	80
Rock, soft, gray	6	86
Rock, igneous, green	32	118
Rock, soft, green (fractured yellowish)	22	140
34/1W-6F2		
Wilmot, Lorrie; drilled by San Juan Drillers		
Till, glacial	16	16
Rock, igneous, grey	145	161
Rock, soft greenish black serpentine		189
34/1W-7G1		
Walker, Charles; drilled by San Juan Drillers		
Sand & silt	37	37
Gravel	1	38
Sand	12	50
Sand, coarse & silt	40	90
Sand, coarse, clean	11	101
Sand & silt	11	112
Gravel	5	117
Sand & gravel	18	135
Gravel	8	143
Sand, coarse	4	147
Gravel & sand	5	152

Material	Thickness (feet)	Depth (feet)
34/1W-7J1		
Olsen, Eniar		
Hardpan, gravelly	33	33
Clay, gritty, blue	19	52
Sand, coarse, water-bearing	14	66
34/1W-7K1		
Jensen, Howard		
Hardpan, gravelly & cobbles	34	34
Clay, gritty, blue	55	89
Sand & gravel, water-bearing	19	108
34/1W-7Q1		
Fischers		
Rock	285	285
34/1W-8K1		
DeBruler, Ralph; drilled by San Juan Drillers, July 16, 1973		
Till, glacial	20	20
Clay, blue	25	45
Sand, fine, brown	20	65
Sand, gray	30	95
Sand & gravel		95
34/1W-9N1		
Cape St. Mary Farm; drilled by San Juan Drillers		
Dug hole	30	30
Clay, blue	46	76
Sand	7	83
Conglomerate	40	123
Rock, hard, black	39	162
34/2W-12P1		
Roosch		
Clay	30	30
Unknown	146	176

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/4W-14B1		
Berhard, Ted; drilled by Martel, September 1972		
Shale, soft, dark gray	430	430
35/4W-14J1		
Collard, R. E.; drilled by Martel, February 1973		
Shale, black	125	125
Basalt, gray	54	179
Clay	10	189
Ash, volcanic	36	225
34/2W-15L1		
Bender		
Clay	4	4
Rock	94	98
34/1W-16D1		
Brady, Floyd L.; drilled by San Juan Drillers		
Clay, brown	36	36
Clay, blue	9	45
(Clay & rock - 40' to 45')		
Clay, sandy, brown	52	97
Rock & gravel	17	114
34/1W-17B1		
Snug Harbor Assoc., Inc., drilled by San Juan Drillers		
Clay, brown	20	20
Clay, blue	32	52
Clay, gravelly	43	95
Sand	10	105
Gravel	40	145
Sand	64	209
Clay, blue	53	262
Boulder	14	276
Shale, gray	9	285
Clay, blue	1	286
Rock, hard, gray green	9	295

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
34/1W-17D1		
Mayo, Ronald D.; March, 1974		
Till, glacial	8	8
Rock, basalt, hard, gray	242	250
34/1W-17F1		
Greenthal, Stanley; drilled by San Juan Drillers		
Sand, gravel, soil	10	10
Rock, hard, dark gray	50	60
34/1W-18B1		
Andrews, Don		
Hardpan, gravelly & cobbles	34	34
Sand & gravel, water-bearing	11	45
34/1W-18E1		
Boroughs, Herbert P., drilled by San Juan Drillers, January 1968		
Dirt, gravel, rock	18	18
Clay, soft, blue	29	47
Gravel	16	63
Rock		63
Gravel	11	74
Sand	13	87
Clay & gravel, water-bearing	3	90
Clay, sand, and gravel	8	98
34/1W-18G1		
Hughes, William E.; drilled by San Juan Drillers, August 1973		
Till, glacial	16	16
Slate, black, veined	100	116
Sandstone, grayish, hard	3	119
Slate, black, veined	34	153
Sandstone, hard, grayish	6	159
Slate, black, veined	66	225

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
34/1W-18G2		
Swanson, Howard L.; drilled by San Juan Drillers, May, 1972		
Sand, gravel, silt	55	55
Sand	29	84
Clay, blue	5	89
Sand, coarse & gravel	25	114
34/1W-18G3		
Thompson, Harry M.; drilled by San Juan Drillers, May 21, 1974		
Till, glacial	21	21
Sand	57	78
Clay, blue	11	89
Claystone	2	91
Sand, gray	30	121
Clay, gravelly, blue	2	123
Gravel		123
34/1W-18G4		
Petersen, Howard S.; drilled by San Juan Drillers		
Till, glacial	16	16
Clay, blue	42	58
Sandstone, brown	34	92
Sand, fine, gray	8	100
Sand & gravel	10	110
34/1W-18H1		
Walvatne, E. L.; drilled by San Juan Drillers		
Till, glacial	14	14
Clay, blue	5	19
Sand	5	24
Siltstone	60	84
Silt, sand, water siltstone	30	114
Sand & gravel		114
34/1W-18M1		
Strain, Don; drilled by San Juan Drillers		
Dirt, gravel, sand	45	45
Rock		45
Sand & gravel	13	58
Clay, gravelly, blue	10	68
Shale & gravel	2	70

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
34/1W-18M2 Rawson, William G.; drilled by San Juan Drillers		
Dirt & rocks	9	9
Gravel, rocky	20	29
Gravel & hard packed sand	9	38
Gravel & loose sand, water-bearing	5	43
Stratified sand, gravel & clay	12	55
34/1W-18P1 Buzzard, Roy; drilled by San Juan Drillers		
Topsoil	1	1
Clay, brown	16	17
Clay, blue	20	37
Sand	20	57
Clay, gravelly, blue		57
34/1W-19D1 Bear, Dean C.; drilled by San Juan Drillers		
Soil, sand, & gravel	11	11
Rock, gray	42	53
Shale	64	117
Rock, gray	19	136
Shale	5	141
Rock, gray	15	156
Shale	5	161
Rock, gray	28	189
Shale	11	200
34/1W-20D1 Weeks, Lincoln; drilled by San Juan Drillers		
Topsoil	3	3
Clay, gravelly, brown	12	15
Clay, blue	22	37
34/1W-20E1 Jans, James; drilled by San Juan Drillers		
Clay, brown	11	11
Shale, gray	153	164

Material	Thickness (feet)	Depth (feet)
34/1W-21H1 Humes Brothers		
Clay	28	28
Rock	97	125
34/2W-2B1 Storms, James; drilled by San Juan Drillers, June 1973		
Topsoil	1	1
Clay, brown	5	6
Gravel	5	11
Rock, gray, hard	64	75
Rock, gray, yellow, green, hard	104	179
34/2W-2F1 Lopez Telephone Company; drilled by San Juan Drillers		
Soil, gravelly	4	4
Clay, rocky, brown	17	21
Clay, blue	9	30
Gravel	4	34
Rock, gray	11	45
Rock, green	1	46
Rock, gray	17	63
Rock, green	3	66
Rock, gray	9	75
34/2W-2P1 Bright, Art; drilled by H. O. Meyer Drilling Co., April 1971		
Predug hole	9	9
Rock, hard	11	20
Rock, hard	383	403
Rock, hard, water-bearing	7	410
Rock	4	414
34/2W-4B1 Dillan, Glen & Solzman, C. M.; drilled by San Juan Drillers		
Topsoil	1	1
Clay & gravel	4	5
Clay, brown	20	25

Material	Thickness (feet)	Depth (feet)
34/2W-4B1 (Continued)		
Clay, blue	29	54
Sand, brown	19	73
Sand & gravel	13	86
34/2W-4B2		
Daries, Bernie; drilled by San Juan Drillers, September 1973		
Topsoil, gravelly & clay, brown	8	8
Clay, brown	13	21
Clay, blue	5	26
Sand	1	27
Siltstone	41	68
Sand	8	76
Sand & gravel	20	96
34/2W-4B3		
Anderson, A. A.; drilled by San Juan Drillers, June 1968		
Topsoil, black	1	1
Soil, sandy	12	13
Clay, blue	39	52
Sand	11	63
Gravel & sand	6	69
34/2W-4B4		
Currier, G. E.; drilled by San Juan Drillers, September 1973		
Topsoil, gravelly & clay, brown	8	8
Clay, brown	28	36
Sand	4	40
Siltstone	11	51
Sand	23	74
Sand & gravel	5	79
Gravel	1	80
Sand & gravel	9	89
34/2W-4H1		
Borton, Clay Jr.; drilled by San Juan Drillers		
Soil, gravelly	3	3
Gravel & sand	6	9

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
34/2W-4H1 (Continued)		
Sand, cemented	60	69
Gravel & sand	21	90
Sand & gravel	28	118
Opened into gravel below		118
34/2W-8E1		
San Juan Associates; June 1963		
Sand and gravel, dry	58	58
Sand, coarse, dry	9	67
Sand and gravel, pebble, water-bearing	36	103
34/2W-12B1		
Mickle, Mike; drilled by San Juan Drillers, June 1974		
Till, glacial	8	8
Rock, igneous, hard, gray	11	19
Slate, hard, gray	1	20
Rock, igneous, hard, light gray	43	63
Slate	4	67
Rock, igneous, hard, light gray	11	78
Rock, igneous, hard, brownish green	1	79
Rock, igneous, hard, gray, green	81	160
Rock, black, narrow band		
Rock, igneous, hard, gray, green	36	196
34/3W-2J1		
National Parks; drilled by Stoican, 1969		
Sand and gravel, boulders	7	7
Clay, gray and sand, coarse, water-bearing	11	18
Clay, gray and sand	29	47
Bedrock (Schist)	64	111
34/3W-2P1		
Cluck and Houghton; drilled by Livermoore, August 1970		
Topsoil	1	1
Sand and gravel	3	4
Seepage (water)	-	4
Hardpan	3	7

Material	Thickness (feet)	Depth (feet)
34/3W-2P1 (Continued)		
Clay, blue, soft	14	21
Water-bearing	-	21
Rock	12	33
Rock (seepage)	-	33
Rock	202	235
Rock, fractured	5	240
Rock, fractured	10	250
35/4W-2N1 Judkins, Robert		
Clay	6	6
Clay, blue	18	24
Gravel	6	30
35/4W-25J1 Koch, George; drilled by owner, September 1970		
Clay, yellow	10	10
Gravel (1" - 2")	7	17
35/1W-2M1 Sam Yak Inc.		
Clay, brown	24	24
Clay, soft, blue	10	34
Clay, hard, blue	9	43
Sand & gravel	6	49
Sand, gravel & silt	5	54
Sand, gravel, silt & blue clay (statified)	16	70
Clay, brown	5	75
35/1W-7R1 Voorhees, Fred; drilled by San Juan Drillers		
Till, glacial	2	2
Sand & gravel	6	8
Rock, green & shale	27	35
Rock, green	41	76
Rock, gray-black	9	85
Rock, green	38	123

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/1W-7R1 (Continued)		
Rock, grayish-white	2	125
Rock, green	55	180
Rock, black	5	185
Rock, gray	5	190
Rock, green & black	10	200
35/1W-18M1 Zoerb, Ron; drilled by San Juan Drillers		
Clay, brown	8	8
Clay, blue	13	21
Clay, gritty, blue	108	129
Sand, thin lenses, water-bearing	4	133
Bedrock	14	147
35/1W-18M2 Richey, Theo; drilled by San Juan Drillers		
Clay, gravelly, brown	18	18
Clay, sandy, blue	57	75
Clay, hard, sandy	10	85
Gravel, coarse sand	3	88
Sand & clay, muddy	10	98
Gravel, coarse sand	3	101
Sand & clay, muddy	12	113
Gravel & sand	2	115
35/1W-18N1 Dickinson, William; drilled by San Juan Drillers		
Topsoil	1	1
Clay, rocky, brown	15	16
Clay, sandy, brown	9	25
Clay, sandy, blue	87	112

Material	Thickness (feet)	Depth (feet)
35/1W-18N2		
Keizer, Lum; drilled by San Juan Drillers		
Clay, brown	21	21
Clay, blue	9	30
Clay, gritty, blue	62	92
Gravel, trace water	1	93
Clay, gritty, blue	50	143
Sand, coarse, water-bearing	11	154
35/1W-18N3		
Nerdrer; drilled by San Juan Drillers		
Clay, brown	8	8
Clay, blue	14	22
Clay, gritty blue	69	91
Gravel, trace	1	92
Clay, gritty, blue	64	156
Sand, coarse & gravel	11	167
35/1W-18N4		
Zoerb, Ames; drilled by San Juan Drillers		
Clay, brown	6	6
Hardpan, blue	12	18
Clay, gritty, blue	65	83
Gravel, water-bearing	1	84
Clay, blue	34	118
Sand, coarse & gravel	10	128
35/1W-19D1		
Arnold, Virgil; drilled by San Juan Drillers		
Hardpan, brown	6	6
Hardpan, blue	48	54
Gravel, trace water	2	56
Clay, gritty blue (till)	90	146
Sand, medium, water-bearing	7	153
34/1W-21M1		
Harried		
Clay	30	30
Rock	255	285

Material	Thickness (feet)	Depth (feet)
35/1W-21P1		
Decatur Shores Investors; drilled by San Juan Drillers		
Unknown	88	88
Rock, hard, black	47	135
35/1W-22B/G		
Schultz, Alvin; drilled by San Juan Drillers		
Clay, brown	15	15
Clay, blue	60	75
35/1W-22C1		
Spurgeon, Dave; drilled by San Juan Drillers		
Clay, brown	12	12
Clay, blue	18	30
Clay, sandy, blue	70	100
35/1W-22C2		
Blanchard, Bob and Stricker, Gus; drilled by San Juan Drillers		
Soil & rock	4	4
Sand & gravel	3	7
Clay, brown & boulders	7	14
Clay, blue	93	107
35/1W-22G1		
Johnson, W. D.; drilled by San Juan Drillers		
Beach gravel	30	30
Clay, Brown	23	53
Clay, blue	7	60
35/1W-22G2		
Carrigan, Jack; drilled by San Juan Drillers		
Topsoil	2	2
Sand & gravel	3	5
Clay, brown	3	8
Clay, blue	20	28
Clay, sandy, blue	42	70

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/1W-22G3		
Burdick, Floyd; drilled by San Juan Drillers		
Clay, brown	18	18
Clay, sandy, gravelly, blue	19	37
35/1W-22G4		
Wood, Frank; drilled by San Juan Drillers		
Clay, rocky	4	4
Clay, brown	28	32
35/1W-22G5		
Nightengale, Robert; drilled by San Juan Drillers		
Topsoil	1	1
Sand	2	3
Clay, brown	15	18
Clay, blue	52	70
35/1W-22K1		
Stewart, A. E.; drilled by San Juan Drillers		
Soil, gravel, rocks	11	11
Clay, blue	14	25
Sand	56	81
Clay, brown	31	112
Clay, blue	123	235
35/2W-23C1		
Orcut, Larry; drilled by San Juan Drillers		
Topsoil	1	1
Dirt & gravel	17	18
Clay, blue	10	28
Gravel	15	43
Sand, coarse & gravel	6	49
Gravel	9	58
Sand	35	93
Gravel & sand	6	99
Sand		99

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/2W-1M1 Williams, John & Donald		
Soil, gravelly	4	4
Bedrock, boulder	2	6
Rock, hard, gray	13	19
Conglomerate	22	41
Conglomerate	40	81
Rock, hard	3	83
35/2W-1N1 San Juan Motel Bldg.		
Topsoil	1	1
Clay, brown	23	24
Clay, soft, blue	30	54
Clay, hard, blue (statified clay & sand)	20	74
35/2W-1N2 North Lopez Service		
Topsoil	1	1
Clay, brown, seepage	21	22
Clay, blue	37	59
Sand & gravel, water-bearing	3	62
Sand, hard & clay	19	81
Sand & clay, statified	32	113
Sand & gravel	7	120
Sand	13	133
35/2W-10J1 Ritchey, Ted		
Clay, brown	18	18
Clay, blue	8	26
Clay, gritty, blue	118	144
Sand, water-bearing		
Gravel, brown sand	42	186
Sand, coarse, blue	27	213

Material	Thickness (feet)	Depth (feet)
35/2W-10K1		
Nason, John Jr.; drilled by San Juan Drillers, October 1973		
Till, glacial	5	5
Sand & silt	67	72
Sand & gravel	63	135
35/2W-10L1		
Vogler, Frank; drilled by San Juan Drillers		
Gravel, rocky soil	15	15
Sand & gravel	30	45
Sand	38	83
Gravel & sand	5	88
35/2W-10L2		
Lowe, John; drilled by San Juan Drillers		
Sand	50	50
Gravel	13	63
Sand	4	67
Gravel	27	94
Sand	5	99
Sand & gravel	36	135
35/2W-11D1		
Brinkley, Hugh; November 1973		
Till, glacial	12	12
Clay, brown	33	45
Sand & silt	17	62
Sand & gravel	6	68
35/2W-11E1		
Zipp, Clem		
Hardpan, gravelly	21	21
Sand, dry, some gravel	161	182
Sand, medium, water-bearing	35	217

Material	Thickness (feet)	Depth (feet)
35/2W-11E2 Endersbe, Dale		
Hardpan, gravelly	8	8
Clay, blue	13	21
Sand, dry, some gravel	150	181
Sand, medium, water-bearing	39	220
35/2W-11M1 Franson, Roy; drilled by San Juan Drillers		
Topsoil, red	1	1
Dirt & gravel	4	5
Clay, rocky, brown	13	18
Sand, fine	67	85
Clay, sandy	8	93
Gravel	2	95
Clay	11	106
Sand	6	112
Sand & gravel	31	143
Sand	10	153
Sand & gravel	4	157
Gravel	18	175
Sand, fine	21	196
Gravel		196
35/2W-11P1 Buffum, Walter; drilled by San Juan Drillers		
Clay, rocky, brown	19	19
Sand & silt	55	74
Gravel & sand	56	130
Clay, gravelly, brown	12	142
Gravelly with strata of shale	17	159
Shale, brown	4	163
Gravel & sand		163
35/2W-12B1 Spencer; drilled by San Juan Drillers		
Dirt & gravel	8	8
Sand & Gravel	43	51
Sand, coarse, dark	21	72
Impervious strata		72
Sand, coarse & gravel	2	74

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/2W-12D1		
Lewis, Dwight; drilled by San Juan Drillers, June 1974		
Till, glacial	5	5
Sand & silt	5	10
Sand & gravel	70	80
Gravel	3	83
35/2W-12F1		
Squillage, Ralph		
Hardpan, cobbles	31	31
Sand & gravel, water-bearing	9	40
35/2W-12F2		
Derer, M. W.; drilled by San Juan Drillers		
Topsoil	1	1
Clay, brown	18	19
Gravel & sand	9	28
Impervious strata	1	29
Sand, coarse and gravel	1	30
35/2W-12F3		
Smaalders, Oscar; drilled by San Juan Drillers, May 1974		
Till, glacial	14	14
Gravel, pea	1	15
Sand	15	30
Sand & gravel	42	72
Gravel	12	84
35/2W-12F4		
Bickerton, John; drilled by San Juan Drillers		
Clay, brown, rocks	10	10
Gravel	9	19
Sand	13	32
Gravel & sand	22	54

Material	Thickness (feet)	Depth (feet)
35/2W-12K1		
Becker, Jay; drilled by San Juan Drillers, May 1973		
Topsoil, brown clay	30	30
Gravel	5	35
35/2W-12K2		
Olsen, Don; drilled by San Juan Drillers		
Soil, black	6"	6"
Clay, rocky	2	2
Clay, sandy	22	24
Clay, blue	43	67
Gravel		67
35/2W-12M1		
Schendel, Royal; drilled by San Juan Drillers		
Soil, rocky	3	3
Clay, gravelly, brown	12	15
Rocks & gravel	5	20
Clay, sandy, brown	30	50
Clay, gravelly, brown	29	79
Clay, sandy, blue	25	104
Sand, fine	21	125
Sand, fine, cemented	22	147
Sand & gravel	6	153
Sand, clayish, brown	17	170
Sand, brown (caving)	4	174
Sand, coarse, clean	6	180
Gravel	12	192
35/2W-14E1		
McLean, Dorothy; drilled by San Juan Drillers		
Clay, brown & boulders	41	41
Clay, gritty blue	61	102
Sand & gravel, water-bearing	11	113
35/2W-14H1		
Goodrow, Forrest; drilled by San Juan Drillers		
Topsoil	6	6
Sand & gravel	4	10

Material	Thickness (feet)	Depth (feet)
35/2W-14H1 (Continued)		
Clay, blue	29	39
Gravel	2	41
Clay with layers of gravel	69	110
Gravel & sand	23	133
35/2W-14J1 Coffelt, Lawrence; drilled by San Juan Drillers		
Clay, rocky, brown	6	6
Clay, blue	114	120
Sand & clay	30	150
Clay, brown	2	152
Clay, blue	13	165
Clay, blue & gravel	114	179
35/2W-15J1 San Juan County Bank; drilled by San Juan Drillers		
Topsoil	3	3
Clay, brown	8	11
Clay, blue	30	41
Gravel & silt, water-bearing	1	42
Clay, blue	31	73
Gravel	2	75
35/2W-15K1 Carpenter, William Sr.; drilled by San Juan Drillers		
Topsoil	1	1
Clay, brown	21	22
Clay, blue	27	49
Sand, blue silt & water	19	68
Clay, sandy, blue	17	85
Sand strata with some gravel		85
35/2W-18E1 Winne, Charles; drilled by Martel, January, 1965		
Sediments, permo-traissic	180	180

Material	Thickness (feet)	Depth (feet)
35/2W-18F1 Island Investment Company; drilled by Martel, January 1968		
Topsoil	2	2
Bedrock or igneous	138	140
Quartz formation, water-bearing	2	142
35/2W-18K1 Channel Vista Water Users Association, Inc.; drilled by Martel		
Topsoil	18	18
Shale, black	82	100
Lava	10	110
35/2W-24A1 Waller, Charles; drilled by San Juan Drillers		
Gravel	4	4
Clay, brown	18	22
Clay, sandy, blue	53	75
Clay, soft, blue	34	109
Clay, hard, blue	5	114
Clay, soft, blue	15	129
35/2W-23E1 Ritchey, Ted		
Clay, blue	22	22
Clay, gritty, blue	79	101
Sand, water bearing		
Gravel	18	119
35/2W-24M1 Springer, Paul; drilled by San Juan Drillers		
Hardpan, gravelly	52	52
Gravel, dry, some sand	212	264
Clay, blue	144	408

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/2W-25B1 Smith, Jan; drilled by San Juan Drillers		
Clay, brown	11	11
Clay, blue	45	56
Sand, very fine, trace water	9	65
Clay, gritty, blue	64	129
Clay, gritty, thin w/b lenses	11	140
35/2W-26C1 Beacher, J; drilled by San Juan Drillers		
First 15 feet hand dug		15
Sand, dry, some gravel	234	249
Sand & gravel, water bearing	15	264
Clay, blue	1	265
35/2W-26L1 Mickle, James; drilled by San Juan Drillers, May 1974		
Till, glacial	18	18
Sand & gravel	142	150
Gravel	25	175
Sand & gravel	65	240
Clay, blue & claystone	9	249
35/2W-26N1 Hughes, Bill; drilled by San Juan Drillers		
Clay, gravelly, brown	18	18
Sand, brown	120	138
Sand & gravel	84	222
35/2W-27A1 Leamer, Mike; drilled by San Juan Drillers		
Clay, brown	12	12
Clay, blue	16	28
Sand & gravel, dry	103	131
Sand & gravel, water-bearing	16	147

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/2W-27B1 Harbor House; drilled by San Juan Drillers		
Depth		78
35/2W-27F1 Davis, Leonard; drilled by San Juan Drillers		
Sand & gravel	39	39
Gravel	11	50
35/2W-28K1 Perkins, Otis & Eleanor		
Sand and gravel	48	48
35/2W-33G1 Bastian, M. A.; drilled by San Juan Drillers		
Till, glacial	1	1
Sand, gravelly clay	40	41
Sand	54	95
Sand, coarse & gravel	9	104
Gravel	24	128
Sand, various grades	20	140
35/2W-33R1 Deach, Chuck; drilled by San Juan Drillers		
Sand & Gravel	49	49
Gravel	18	67
Sand, cemented	12	79
Clay, blue	8	87
Clay, sandy	10	97
Sand	41	138
Gravel	3	141
Sand, coarse & gravel	33	174
Sand, medium	16	190
Gravel	18	208

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/2W-33R2		
Lopez Golf Club; drilled by San Juan Drillers		
Marsh Soil	1	1
Clay, rocky, brown	7	8
Clay, blue	59	67
Sand, brown	21	88
Sand, gray	3	91
Sand & gravel, stratified	71	162
Sand, fine	33	195
Sand, fine & small amount of gravel	7	202
Sand, very fine	10	212
Clay, brown	19	231
Clay, blue	34	265
35/2W-33R3		
Island Golf Club Inc.; drilled by San Juan Drillers		
Soil	1	1
Clay, rocky, brown	7	8
Clay, blue	59	67
Sand, brown	21	88
Sand, gray	3	91
Sand, stratified & gravel	71	162
Sand, fine	33	195
Sand, fine & some gravel	7	202
Sand, very fine	10	212
Clay, brown	19	231
Clay, blue	34	265
35/3W-3B1		
Taylor, Mrs. Charles; drilled by Brown		
Earth, dirt	14	14
Shale	206	220
35/3W-23G1		
Larson, Alvie; drilled by Livermore & Son, Inc., May 1963		
Sand & gravel	2	2
Hardpan & gravel	8	10
Rock, gray	8	18
Rock, very hard, black	71	89
Rock, hard, black & green	17	106

Material	Thickness (feet)	Depth (feet)
35/3W-23G1 (Continued)		
Rock, green	22	128
Rock, hard, black & gray, water-bearing	24	152
Rock, very hard, green, some quartz	4	156
Rock, black, water-bearing	26	182
Bottom		190
35/3W-23J1 Loring, Rober; drilled by Livermore & Son, Inc., April 1967		
Topsoil	1	1
Sand & gravel	2	3
Sand, dry	8	11
Sand & clay, blue	3	14
Bedrock, black, some quartz seams	173	187
35/3W-26A1 Christenson, Charles & Larena; drilled by Livermore & Son, Inc., September 1964		
Sand & gravel	3	3
Sand, gravel & hardpan	12	15
Clay, sandy, blue	4	19
Bedrock, black, some quartz seams	25	44
Quartz seams, water-bearing	53	97
35/3W-27J1 Rogers, H.E.; drilled by Brown, 1965		
Overburden	15	15
Rock	66	81
35/3W-28D1 San Juan Ranchos Club Inc; drilled by Brown, February 1972		
Clay	45	45
Rock, gray, hard	116	161

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
35/3W-30Q2		
Hannah Heights, Inc.; drilled by Martel, December 1971		
Sand and gravel	18	18
Basalt, medimum soft, dark gray	182	200
Basalt, hard, light gray	55	255
35/3W-32D1		
Kilpatrick, W.S.; drilled by Martel, October, 1969		
Topsoil	13	13
Rock, igneous	129	142
Quartz	18	160
36/1W-15D1		
Russell, R. J.; dug by Rodenberger, October 1969		
Topsoil	2	2
Clay, brown, hard	5	7
Clay, blue, soft	19	26
Clay and sand, blue	2	28
36/1W-15P1		
Virginia Lands, Ltd.		
Rock	292	292
36/1W-15P2		
Virginia Lands, Ltd.; drilled by Brown, 1973		
Drift, glacial	46	46
Rock	237	283
36/1W-15Q1		
Larson; dug by Rodenberger		
Drift, glacial	26	26

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
36/1W-16Q1		
Tartarini, C. P.; dug by owner, July 1948		
Topsoil	1	1
Clay, hard	4	5
Sand and gravel	3	8
36/2W-6J1		
Shevlin, J. D.; drilled by Brown, October 1959		
Clay	20	20
Rock	120	140
36/2W-6H1		
P.E.T.S., Inc.		
Clay, hard	8	8
Limestone	182	190
36/2W-4P6		
Kelton, R. J.; dug by Owner, 1912		
Clay	15	15
36/2W-4P2		
Van Fleet, A. B.		
Clay, white	14	14
Sand	2	16
36/2W-4P1		
Van Fleet, A. B.; dug by Torie, October 1964		
Clay, white	16	16
Sand, water-bearing	3	19
36/2W-7E1		
North, C. L.; drilled by Brown, August 1972		
Clay	10	10
Shale	30	40
Limestone	146	186

Material	Thickness (feet)	Depth (feet)
36/2W-7F1 Fredrickson, W. L.; drilled by Brown, October 1972		
Clay	12	12
Rock	102	114
Unknown	12	126
36/2W-7H1 Gaggs, M. T.; drilled by Brown, August 1963		
Shale, gray, metamorphosed	68	68
Shale, broken, water-bearing	2	70
Shale, gray and black layers, metamorphosed	173	243
Shale, greenish-gray, shattered	5	248
36/2W-7K1 Bush, L. K.; drilled by Brown, October 1967		
Loam, black	2	2
Clay, blue-gray	80	82
Limestone, gray	100	182
36/2W-9C1 Van Fleet, A. B.		
Clay, white	14	14
36/2W-9C2 Van Fleet, A. B.		
Clay, white	11	11
36/2W-15N2 Hastings, J. W.; dug by Rodenberger, August, 1970		
Topsoil	1	1
Clay, rocky	3	4
Sand, some clay	8	12
Clay, blue, sandy	10	22

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
36/2W-15N3		
Orcas Landing Inc.; drilled by Brown		
Clay	16	16
Rock, soft	253	269
Unknown	16	285
36/2W-15N4		
Tupper and Head; dug by Rodenberger, September 1948		
Topsoil	3	3
Clay, blue	18	21
Sand	6	27
36/2W-16A1		
Chapman, C. E.; drilled by Brown, May 1966		
Topsoil	2	2
Rock	159	161
36/2W-18A1		
Coffman, E. F.; drilled by Brown, June 1959		
Unknown	30	30
Rock	195	225
36/2W-18B1		
Howland, M. A.; drilled by Tift, June 1957		
Clay and till with boulders	85	85
Shale, gray and black, metamorphosed, broken, water-bearing	176	261
36/2W-21A1		
Skyland Enterprises; drilled by Brown, May 1963		
Clay, brown	20	20
Clay, blue	30	50
Sand, fine	10	60
Rock, solid, gray, with limestone	65	125

Material	Thickness (feet)	Depth (feet)
36/2W-21A2		
Orcas Landing Inc.; dug by Rodenberger, August 1966		
Topsoil	2.5	2.5
Clay	7.5	10
Sand	19	29
36/2W-21A3		
Orcas Landing Inc.; dug by Rodenberger, September 1966		
Topsoil	2	2
Clay, blue, soft	16	18
Clay, blue, soft, sand and shells	7	25
36/2W-22C2		
Russell, F. C.; dug by Rodenberger, November 1971		
Topsoil	5	5
Sand and gravel	9	14
Sand and gravel, shells, water-bearing	4	18
Clay, blue	16	34
36/3W-1A1		
Gearhead, R. F.; drilled by Brown, September 1963		
Clay and hardpan	20	20
Shale	50	70
Limestone	80	150
36/3W-1G1		
Westmont; drilled by Brown, December 1964		
Topsoil	15	15
Bedrock	95	110
Shale, fractured, water-bearing	15	125
36/3W-13A1		
Washington House; drilled by Brown, 1969		
Clay and gravel	100	100
Bedrock, sepentine	180	280

Material	Thickness (feet)	Depth (feet)
36/3W-13B1 Washington House; drilled by Brown, 1969		
Overburden	30	30
Some water		50
Rock, not serpentine	300	350
36/3W-13B2 Washington House; dug by Rodenberger, 1969		
Clay, blue, with seepage	11	11
36/3W-13B3 Washington House; dug by Rodenberger, 1969		
Clay, blue, with seepage	14	14
36/3W-17E1 Roche Harbor Lime and Cement Co.; drilled by L. R. Gaudio Well Drilling Co., June 1959		
Topsoil	2	2
Sand, gravel, boulders	12	14
Clay, blue & boulders	6	20
Gravel, cemented, gray	3	23
Sand & gravel, tight packed	3	26
Sand & gravel, water-bearing	6	32
Clay & gravel	2	34
Sand & gravel	6	40
Clay, blue	6	46
Clay, blue & boulders	2	48
36/3W-17E2 Roche Harbor Lime and Cement Co.		
Mud and gravel, packed	6	6
Sand (dry)	9	15
Sand, thin layers blue silt, some water	5	20
Silt, sandy, blue, with sand layers	10	30
Dirty mud & gravel, some water	4	34
Hardpan, blue & boulders	8	42

Material	Thickness (feet)	Depth (feet)
36/3W-18C1		
Durhack, Roy; dug by Woods, September 1964		
Topsoil	1	1
Clay	24	25
36/3W-18H1		
Roche Harbor Lime and Cement; drilled by Gaudio, 1959		
Sand and gravel, dry	6	6
Sand, some water	2	8
Sand, packed	5	13
Clay, blue and gravel, boulder	25	38
36/3W-18K1		
Roche Harbor Lime and Cement Co.; drilled by Gaudio, 1959		
Sand & gravel (dry)	9	9
Sand (dry)	37	46
Sand, alternately tight & loose	32	78
Clay, silty, yellow	3	81
Clay, silty, blue and sandy silt	27	108
Silt, hard, blue, some boulders	10	118
Clay, yellowish gray	9	127
Gravel, cemented, some boulders	4	131
Rock	6	137
36/3W-20M1		
Nash, E. H. and Agnes; drilled by Brown, 1970		
From geologic map - mostly TR conglomerate; graywacke, gritstone, limestone		205
36/3W-20M2		
Cary, Carl and Mary; drilled by Martel Well, July 1970		
Topsoil	34	34
Meta-sediments	206	240

Material	Thickness (feet)	Depth (feet)
36/3W-20N1 Best, Bruce; drilled by Martel, February 1973		
Shale, black	145	145
Rock, limestone	15	160
Basalt, gray	80	240
Shale, black	20	260
36/3W-20N2 Asher, Paul; drilled by Martel		
Shale, black	145	145
Rock, lime (limestone)	15	160
Basalt, gray	80	240
Shale, black	20	260
36/3W-29C1 Millman, Vern		
Topsoil	20	20
Metasediments (geologic map)	180	200
36/3W-34D1 Jorgensen, Hans; drilled by Brown, February 1970		
Clay	16	16
Rock	235	251
36/3W-34Q1 Hicks, L. A.; drilled by Tift, December 1956		
Limestone relatively soft all the way		240
36/4W-13G1 McDuffie, Maynard; dug by owner, September 1958		
Clay, blue		6

Material	Thickness (feet)	Depth (feet)
36/4W-13G2		
Hayssen, Leonard; drilled by Brown		
Clay	18	18
Rock	132	150
36/4W-23N1		
Anderson, Dick & Walter Walkinshaw; drilled by Jannsen, March 1939		
Clay	26	26
Boulders	6	32
Rock	103	135
36/4W-26L1		
Gaynor, Virginia; drilled by Brown, September 1974		
Clay	14	14
Rock	117	131
36/4W-35D1		
King, Clyde and Keturah; dug by Woods, October 1970		
Topsoil	2	2
Subsoil	1	3
Clay	15	18
Bedrock		
36/4W-35E1		
Brazda, Frank; drilled by Brown, June 1962		
Overburden	22	22
Shale with quartz	248	270
36/4W-35F1		
Rogers, Walter Sr.; drilled by Tift, January 1961		
Overburden	18	18
Rock, solid	184	202

Material	Thickness (feet)	Depth (feet)
36/4W-35F2 Briggs, Dorothy; drilled by Brown, March 1965		
Clay and hardpan	20	20
Shale and quartz	135	155
37/1W-7P2 Buckhorn Lodge		
Topsoil	15±	15±
Sandstone and granite	485	500
37/2W-10K1 Chambers, Grant		
Topsoil	20	20
Rock, solid	264	484
37/2W-11H1 Clark, C. R.; drilled by Enlow, 1950		
Hardpan	30	30
Clay, blue	65	95
Clay, blue, with gravel, fine	3	98
Gravel	2	100
37/2W-11J1 Wright, Frank		
Sand	86	86
37/2W-11R1 Jensen, H. W.; drilled by Keith		
Clay, blue	51	51
Sand, water-bearing	34	85
Gravel, coarse, water-bearing	15	100

Appendix Two -- Drillers' Logs of Representative Wells -- Continued

Material	Thickness (feet)	Depth (feet)
37/2W-12E1 Campbell, Robert; drilled by Enlow, 1950		
Soil and gravel	8	8
Clay	55	63
Sand, fine, gray, water-bearing	3	66
Clay	29	95
Sand, brown, water-bearing	5	100
Clay	20	120
37/2W-12N1 Ammerman, Leland		
Clay, sand, and gravel	230	230
37/2W-12P1 Brakeman, Clarence; drilled by Tift, 1953		
Hardpan	17	17
Clay, hard, blue	73	90
Gravel, fine and clay, blue	7	97
37/2W-13B1 East Sound Water Dist.; drilled by Jannsen, April 1955		
Overburden and clay	30	30
Sand, gravel and till, glacial	20	50
37/2W-14F1 Leatherwood, Fred; dug September 1958		
Loam, sandy	2	2
Gravel	10	12
37/2W-14H1 Harrison, Max; dug March 1954		
Hardpan	15	15
Sand, quick, water-bearing	5	20